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Transactions

AMERICAN FOUNDRYMEN'S ASSOCIATION

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A.F.A. Foundation Lecture—1943

Foundry Metallurgy in the Castings Industry

BY JOHN W. BOLTON*, CINCINNATI, O.

FOREWORD

THE writer is deeply appreciative of the honor so graciously bestowed upon him by inviting him to present this, the first Foundation Lecture of the American Foundrymen's Association.

It was suggested that this lecture be a general review of progress, specifically metallurgical progress, in the castings industry. It was requested that consideration be given to the branches of the art as included under the five major divisions of the Association.

Foundry metallurgy is but one factor in one industry, and industry is in turn a significant element in modern civilization. Failure to integrate industrial advance and political economy has contributed to the chaos of today.

The writer was and is acutely aware of the difficulty of properly complying with the assignment. The breadth of field (combined with limitations in experience and knowledge) and the desirability of condensing the presentation, are among the problems presented. On the one hand, as an individual, he has been considerably humbled when viewing the scope and significance of our foundry problems. On the other, as a member of the Association, he is optimistic, yes, enthusiastic about the possibilities of progress, and especially the possibilities of progress within and by our Association.

It is a practice in some societies and associations to establish lectureships named for some distinguished individual. Commendable as this practice may be in some respects, a not unusual result is some restriction in subject matter to or toward the field of endeavor of the individual. For the Foundation Lectures of the American Foundrymen's Association, restriction is but to the castings industry. There is a rich heritage of knowledge and inspiration, not from one but from many men, upon which an enduring series of Lectures could well be built. While fully cognizant of the extensive and splendid work done by other technical groups, and by many individuals, in the United States and Canada as well as abroad, the far greater portion of the review and references is confined to the work of this Association, as revealed in its Transac-

* Metallurgist, The Lunkenheimer Co.

tions. By this procedure we see not alone what the Association has done, but also where coverage might be extended. Fortunately most workers in the foundry art have contributed their studies to the Association. Included among these are a number of the distinguished workers of other countries.

It is not a purpose of the Association to promote one branch of the industry at the expense of another, nor to promote castings through criticism of the products made by other processes. The objective of the Association is to encourage the assembly of technical information and to disseminate it—to promote improvements in products and processes, and to see that the engineering world has placed before it reliable and complete information, so that intelligent selection can be made.

FOUNDRY METALLURGY—INTRODUCTORY

Progress in the art and science of foundry metallurgy during the period between the great world wars has been rapid, and accelerative in rate. This has been reflected in quality of product, economy of manufacture, engineering application and in the competitive position of the industry. The dictionary defines metallurgy as "The science and art of extracting metals from their ores, refining them, and *preparing them for use.*" Foundry metallurgy is the science and art of preparing metals for usage in engineering structures through the medium of casting processes. As such it is concerned with the selection of raw materials, their melting, casting, and treatment, both incidental and subsequent, to the point of fabrication beyond the cast form. By the term casting is implied study and control of gates and risers, the sand or other media and other related phases of the foundry art. By the term incidental treatment is implied such procedures as inoculation, duplexing, deoxidation, and so on. By the term subsequent treatment, such operations as heat treatment are inferred, including repair welding, to the point of fabrication by machining, assembly welding or the like.

The metallurgist uses various general sciences such as physics and chemistry, and also more specialized branches of science, for example metallography. He also uses or adapts many arts. Most foundry problems resolve themselves into the interrelationships of three factors, namely composition, temperature and time. Time (more specifically, rate of reaction) is the least understood of these factors, hence highly promising for future study. To these may

be added the problems of mechanics, pressure, flow, and other related matters.

Materials handling or transportation, the direction and management of labor, and other factors of the sort are aside from foundry metallurgy as such. The economic aspects of such factors are well realized by management, and great importance rightly is attached to them. Too frequently it is not realized that foundry metallurgy also has economic significance, and is in the long run a sound basis or starting point from which to build up a truly integrated foundry business, and a strong industry.

Service Per Dollar

The ultimate objective is to provide a suitable material of construction at a price which will permit successful competition with other materials of construction. It should be realized clearly that the foundry sells service per dollar rather than pounds of castings. Serviceability of the material in the casting is determined by the foundry metallurgy behind it. For given serviceability of material in a casting, foundry metallurgy often affords a number of approaches. Among these, choice can be made on the basis of cost or economy.

GRAY IRON

An objective review of the status of gray iron metallurgy, and of the degree of acceptance of gray iron as a worthy engineering material, indicates two things quite clearly:

First, in real competition, it must be sold on its merits—on the service per dollar basis rather than on a pounds per dollar basis.

Second, practical improvement and scientific elucidation have gone rather closely hand in hand—a trend that probably will continue.

Gray iron has been improved in reliability, uniformity, and range of properties available. Much is known about its useful, and, for some services, unique, engineering characteristics. The actual properties of the metal in castings (as opposed to test bar data) have been studied to a degree not exceeded and perhaps not equalled in the case of other metals, cast or wrought. Excellent specifications are available from which the consumer can prescribe safely and surely.

Despite this, there remains considerable prejudice against gray iron. The terms weak, brittle, unreliable and the like still are ap-

plied to it by many uninformed engineers. Unfavorable presentations are contained in some handbooks and other publications. Gray iron has not gained the confidence and trade acceptance that it merits.

This branch of the castings industry is far the largest in tonnage production, it has the greatest number of units, and product applications are greatly diversified. Until recently it has not been very well coordinated; also, it has not been distinguished by being articulate.

Ease with which melting can be conducted and with which reasonably sound gray iron castings can be made has not been entirely fortunate. Many could "get by" without technology. To make high quality metal to rigid specifications requires much in the way of foundry metallurgy and control. It is not merely a question of the best material, but the best material at the least cost. Anyone can make an article cheaper; anyone can improve its quality. The art lies in combination of these achievements.

Structures Complex

Gray irons are a different and in several respects a more complex series of alloys than cast steels, principally because of the formation and presence of an additional and significant structural component, flake graphite which is formed during the initial casting process.

In the case of cast steel a valuable heritage is available from the studies of wrought steel. This has lessened the amount of pioneering research needed, and often has enabled cast steel foundrymen to take advantage of adaptations. In contrast, the gray iron industry has had to work out most of its own metallurgical problems.

Changes in Technology

Twenty years or so ago emphasis was on composition. Chemical analyses had displaced the older methods of judging by fracture. Great stress was laid on percentages of combined carbon, silicon and sulphur, some on phosphorus and manganese, and little or none on percentage of total carbon.

Subsequent metallurgical progress has followed several fairly well defined lines, as follows:

- (1) Study of the general relationships of structure to mechanical properties.
- (2) Determination of the significance of total carbon content.

(3) Study of how factors beyond mass and silicon content (and the usual "elements") may influence structure and mechanical properties.

(4) Classification and specification of irons according to section and strength properties.

(5) Study of mechanical characteristics and their interrelationships beyond the transverse test and the infrequent tensile tests of twenty years ago.

(6) Developments in the techniques of sand control, melting, molding, heat treatment, etc., and of new and improved testing methods.

Beyond a few worthy exceptions, little has been done to gather and make public reliable data on the behavior of gray iron, particularly the improved classes, in actual engineering service. This neglect has been an important factor in preventing proper and full capitalization of the developments previously mentioned. In certain fields—automotive and enamelling for example—some data have been made public. Engineers and designers are more readily convinced by demonstration than by physical test charts.

Howe and Elliott

Seeds from whence many developments of the last twenty years or so have grown were sown by two men. One, Henry Marion Howe, is known and honored by all ferrous metallurgists. The other, George Koch Elliott, author of the first A.F.A. Exchange Paper, is remembered by but few.

Howe's restless and probing mind delved into nearly every phase of ferrous structural metallurgy. He sought tirelessly to bring about system and order. His direct work in gray iron was limited, but his teaching was clear, his suggestions significant, and his logic relentless. He emphasized the possibilities of (1) and (2) in the above outline of metallurgical progress.

As an experimenter Elliott was far ahead of his time. In exposition he was modest, and overly cautious in hypothesis and speculation. From a practice viewpoint, he was a pioneer in the development of electric furnace melting and duplexing, as under (6) above. His observations on the effects of superheating—as developed by him—are the foundation upon which much under (3) above is based. To the factors of composition and time (then recognized if not well understood) Elliott added temperature above the liquidus. Subsequent publications by others on superheating would fill a large volume. Ideas about undercooling, nuclei, inoculants

and the like are logical sequences to the original observations of Elliott.

Developments in Early Twenties

In the early twenties specific foundations for much of the subsequent American development in gray iron metallurgy were laid through the close cooperation of a small group of men—among them Ralph MacPherran, Hyman Bornstein, James MacKenzie, Willard Rother, James Vanick and Alfred Boegehold. Efforts were made to evaluate cast iron objectively, as a worthy engineering material, and particularly to get away from the prevailing specifications based on the so-called "quality of iron in the ladle." Studies of structure and mechanical properties showed that composition or analysis is in itself but one factor, and not a suitable basis for selection or prescription.

Rother and Mazurie¹ discussed effects of mass; MacPherran and Harper² considered heat treatment; MacKenzie³ probed the effects of phosphorus on carbon; Vanick and Wickenden⁴ discussed the influence of nickel; while Bornstein and Boegehold were active in committee organization, specification formulation and like endeavors.

These and other papers of the early twenties thoroughly awakened workers to the practical possibilities of scientific approach. There was established a closeness of cooperation, of teamwork, of objective approach, which is retained to this day. Many contributions have followed, adding to our useful knowledge both of the *why* and the *how* of gray iron metallurgy.

There was marked progress in other countries. In Great Britain most of this centered in the excellent work of the British Cast Iron Research Association under the leadership of J. G. Pearce. On the continent Piwowarski and associates were perhaps the most prolific workers. Nor do we forget that splendid Englishman, John Shaw, whose keen analyses, probing criticism and friendly advice were so helpful to all young research workers.

Use of the electric furnace (direct and indirect arc), duplexing,

¹ Rother, W. H., and Mazurie, V., *The Strength of Cast Iron in Relation to Its Thickness*. TRANSACTIONS, American Foundrymen's Association, vol. 34 (1926), pp. 746-765.

² Harper, J. F., and MacPherran, R. S., *Annealing Gray Cast Iron*. TRANSACTIONS, American Foundrymen's Association, vol. 30 (1922), pp. 167-180.

³ MacKenzie, J. T., *The Influence of Phosphorus on the Total Carbon Content of Cast Iron*. TRANSACTIONS, American Foundrymen's Association, vol. 33 (1925), pp. 445-467.

⁴ Wickenden, T. H., and Vanick, J. S., *Nickel and Nickel-Chromium in Cast Iron*. TRANSACTIONS, American Foundrymen's Association, vol. 33 (1925), pp. 347-425.

superheating, large hot blast cupolas, and the production of high strength irons on a tonnage basis, were in considerable degree American achievements, as was also the use of "alloys."

Molding methods, including centrifugal casting, permanent molds and the like, were advanced during this period. Splendid developments were made in sand testing technique.

It is significant that the A.S.T.M.-A48 specifications were the first to make provision for classes of commercially available high strength irons, including classes to 60,000 p.s.i. minimum tensile strength.

Symposia Presented

A "Symposium on Physical Properties of Cast Iron" was presented before the A.S.T.M. in 1929. As stated at that time by Bornstein, "In case of steel, rapid progress has been made during the past two decades in classifying various types of steels and determining their physical properties. As a result the engineer has become familiar with the large range of steels and is able to select a material which suits his particular purpose. There has not been the same progress in the classification of cast irons and the determination of their physical properties. Furthermore accurate information has not been widely disseminated to the engineering profession. As a consequence the engineer frequently has looked with suspicion on cast iron as an engineering material—specifications have not caught up with practices—knowledge as to its properties is necessary to encourage its proper use in industry." A review of this symposium, and especially the discussion is well worth while. A later A.S.T.M.-A.F.A. Joint Symposium was presented⁵ in 1933.

Since that time many more data have become available. A considerable portion is contained in the *Cast Metals Handbook*⁶. Despite this, it is evident (and this has been true especially in this war) that the objectives expressed and implied by Bornstein remain too far from fulfillment. It is hoped that the program being presented at this meeting by the Gray Iron Division and made possible by the Association and its chapters will prove effective.

What Is Gray Iron?

Years ago Howe asked "What is steel?" Today a group of earnest workers are asking "What is cast iron?" and are search-

⁵ Symposium on Cast Iron, presented before joint meeting of A.S.T.M. and A.F.A. June 26, 1933, PROCEEDINGS, A.S.T.M., vol. 33, Pt. 2 (1933), pp. 115-273.

⁶ *Cast Metals Handbook*, A.F.A. 1940 Ed.

ing out the fundamental mechanisms of structures. As an absolute science we will never know, but as the broad pattern is woven by the skilled labor of many minds and hands, here and abroad, we will understand better the things with which we work, and can manipulate them better to useful ends. Sometimes "practice" may forge far ahead—as was the case with Elliott's superheating. Sometimes "theory" may lead—when certain advantages of lower carbons became apparent, methods were adopted or devised to produce them. But the art and science of foundry metallurgy covers both.

Some thirty-four workers in the field of structural studies are represented in the Transactions over the past five years. It is encouraging to note that many of these are younger men.

Practical operating methods and engineering developments too have received their share of attention. Some seventeen workers are represented in the Transactions of 1937-1942.

Comparison of Presentations

Beginning in the early twenties and up to 1930 the writer presented thirty or more papers to several agencies including the Association. These sought to demonstrate the practical importance of the graphite flake formations through their size, distribution, and similar characteristics. It was shown that there are relationships between graphite distribution and the position of the alloy in the iron carbon diagram. Some of the effects of mass on structure and on engineering properties were mentioned. A scheme for classification of flake structures was proposed. Direct proof was given that fracture (in large measure) follows the flakes. Influence of total carbon on structure, degree of quasi-isotrophy, and strength was considered.

More purely mechanical questions, such as mechanisms of deformation and creep characteristics, also were studied, along with such problems as the structures of the phosphorus rich constituents, effects of pouring temperature, questions of heat treatment, and so on.

In the course of the review preceding preparation of this Lecture it was interesting to compare some of these earlier papers with modern ones, such as those delivered before the Association during the past four or five years.

Today's presentations of other workers are much more refined. They reflect the general advances in science. Better techniques are evident, new viewpoints are brought to bear. Gaps in knowledge

are being filled, older findings confirmed or modified. In that period, some ten to twenty years back, there was but little interest in structural metallurgy. The writer was among those who attempted to arouse interest in the then newer approaches, and often over simplified and avoided details to get the message across. That is no longer necessary. Today even highly technical presentations get a large and understanding audience. Yes, today's presentations are on a distinctly higher plane. Even so it is whispered to a few of the younger workers that wider reading, more extensive bibliographic study, and more effort to gain direct operating experience would not come amiss.

Composition, Time, Temperature

Whatever gray iron is or may be depends upon composition, time, and temperature. In that statement the matter of density or soundness is not neglected, since flow, feed, and solidification are related to composition, time and temperature. Internal stresses also are affected by these factors.

Gray iron is essentially an alloy of iron and carbon. Its properties depend largely upon the amounts and arrangements of the carbides and ferrite in the matrix, and on the degree of discontinuity of the matrix that is effected by the graphite flakes. We start with a certain amount of iron and of carbon.* The other elements (major and minor), time and temperature determine the condition of the carbon and hence of the resulting product.

Speaking somewhat broadly for scientific accuracy we might consider many effects of the other elements (including alloys) within the factor time, because they influence reaction rates. Certain ones also change the critical range temperatures, and some, notably silicon, alter markedly the percentage of carbon required for the eutectic concentration. Inoculants, gases, and like agents may be included along with the "elements."

Directly speaking, time may be considered in terms of rates (as in effects of mass) or, as in heat treatment (even in flame hardening), an elapsed period.

In research it is too easy to get away from fundamental factors and to get lost in a maze of unrelated details. Happily, several among the recent papers in the Transactions indicate clear conceptions of the fundamentals. There remains room for more compre-

* Discussion of phosphorus formations, inclusions and also consideration of austenitic iron etc. is avoided for sake of brevity.

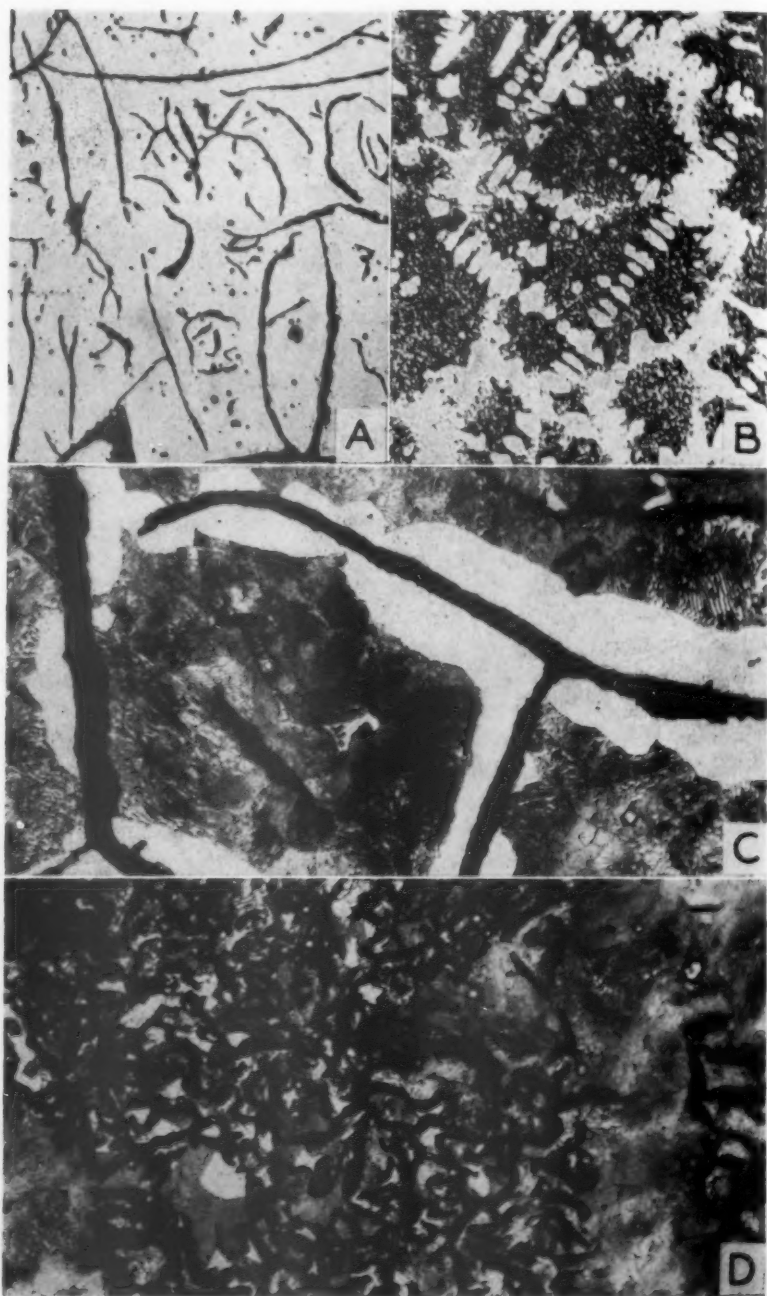


FIG. 1—(A) TYPICAL PIG IRON STRUCTURE—100 DIA., UNETCHED.
 (B) MODIFIED PIG IRON STRUCTURE—100 DIA., UNETCHED.
 (C) TYPICAL PIG IRON STRUCTURE—500 DIA., ETCHED.
 (D) MODIFIED PIG IRON STRUCTURE—500 DIA., ETCHED.

hensive and thoroughly coordinated research. Perhaps thorough correlation of work published to date, including the most recent, would be helpful, not alone in indicating the gaps, but in giving a more readily attainable grasp of the panorama.

Your indulgence is requested to permit the posing of one question. Will real control of graphite shape be realized in gray iron?

Its amount can be controlled and considerable information is known about size and distribution. Visualize a material, possessing (as cast) graphite flakes or groupings resembling those of malleable iron instead of groupings of elongated flakes. We are accustomed to accept flake shapes. Such claims as have been made purporting to change them are not too convincing. At most, any accomplishments in that direction are modest.

Dogmatists will say that absolute control of flake shape (or elimination of flake formation) is an impossibility. They will cite many reasons, real or alleged. What is an impossibility? That a thing has not yet been done, does not make it an impossibility.

For example the writer has seen a very uniform graphite structure produced in markedly hypereutectic pig iron. (Fig. 1, gray iron photomicrographs.) None of the large and plate like flakes, or "kish," typically characteristic of hypereutectic iron, could be found even in heavy sections. (Figs. 1B and 1D.) There was no chill. An iron of almost identical major composition cast into the same pig mold showed the heavy kish flakes. (Figs. 1A and 1C.) If the characteristic plate like formation can be modified fully, may there not be possibilities in the eutectiferous and hypoeutectic irons? Commercial exploitation of such products would not be difficult.

Specifications Selection and Prescription

It is unfortunate that many have not given specifications (a "measuring stick" of the engineering worth of a product) the consideration they deserve. Too often specifications are viewed as afflictions. A positive and constructive attitude, personal interest, and personal support are needed. If specifications are considered inadequate, there certainly is a welcome awaiting those willing to help in making them better and more useful. If testing methods have shortcomings, or better methods are desired, any technical committee will greet with open arms all who are willing to work.

To get the right iron the customer must select the proper class for his service, on the basis of strength desired and section size involved. A.S.T.M. Specification-A48 (first adopted in 1932) offers such a basis for selection and prescription. This specification is well grounded on a basis of careful studies. The British had issued a specification based on the same principles in 1930 or 1931. Both groups had been working along similar lines for several years. The majority of published research data preceding the issue of either specification was of American origin. Several months ago an editorial of the British Foundry Trade Journal stated that the preparation and issuance of the British specifications was and is one of the greatest forward steps in gray iron in many years.

A.S.T.M.-A48 and the Federal QQ-I-652 are alike in principle and agree in most details. Similar general principles also are followed in German and Japanese specifications.

It is not argued that specifications are a substitute for the integrity and skill of the manufacturer. They are supplementary, and of greatest value as an objective measuring stick, subject to independent tests or other check. Specifications calling for "good grade gray iron," "high class semi-steel" and similar indefinite designations have no engineering significance. Trade names have a legitimate place, but when it is claimed that XYZ alloy is the "missing link between cast iron and steel" and so on and so on, and prescription by actual independent test is avoided, it is evidence of intellectual dishonesty which does not engender confidence in the material in general, however effective it may be in a temporary way and with less informed individuals.

Cooperation

Despite the fact that advances in the foundry metallurgy of gray iron have been considerable, efforts made toward exploitation of the product have not been too successful. Customer confidence that insures product acceptance has not been too well established.

Perhaps this is partly true because, in the past, major support for research, and direct conduct thereof has come from captive foundries, from metals vendors, and from universities and similar institutions. With but few noteworthy exceptions jobbing foundries often have not participated directly.

The writer believes that all concerned recognize a need for continued research and development. Perhaps many who would like to participate do not know just how to go about it. They are

properly cautious about spending money without seeing clear and effective plans before them. Some perhaps find it hard to visualize the value of research in maintaining and improving the competitive position of an industry.

In supporting work that is of benefit to a whole industry, organizations often find that the ultimate objectives are reached thus most swiftly and surely. Cooperation is not mere altruism, it is intelligent selfishness.

The problems of cooperation challenge all of us, both as individuals and as members of technical and trade groups. The will to do, to accomplish, exists. To crystallize it, to organize it, to lead it, is a task partly done. It well can be pursued further.

Attention should be called to the useful engineering characteristics of gray iron, wherein they are superior to those of other materials of construction. There should be some gentle "debunking" of the comparisons (?) made with some other metals. What engineering significance *per se* has the reduction of area? Directly applied, just what use is one going to make of 30 per cent elongation? What is the value of a minimum of 35 ft. lb. Charpy impact where highly dynamic loading is not met? Such competition, inferring that gray iron is a weak, brittle, unreliable metal, hardly indicates constructive selling. It has been said that the designer is "ductility crazy." Assuredly making this property a *sine qua non* is not a balanced approach.

Gray irons are available over a wide range of tensile strengths. Long time tests show that a large percentage of the ultimate tensility is usable—in contrast to the comparatively low limiting strengths—the yield strengths—of many other alloys. The compressive strength of gray iron is relatively high. In transverse loading its rupture modulus is high in comparison to its tensility. It is relatively insensitive to notch effects, which sometimes make quite ductile metals unreliable. Its fatigue strength is a very respectable percentage of its ultimate strength. It possesses unique damping properties. Its non-seizing properties in metal to metal wear are excellent in comparison to many metals. It is hoped that at this meeting many examples of successful applications of gray iron will be made available. A few examples of successful field applications are more convincing than sheets of unsupported statistical data.

Summary

This gray iron section of the Lecture purposely emphasizes cer-

tain broad trends in the industry rather than detailed and specific technical developments.

Technical achievement—and it has been considerable—has not been fully capitalized. Customer acceptance has not paralleled technical advance. War is bringing this fact home most vividly. It is also upsetting many cherished practices. Profligate usages of materials, and employment of uneconomical methods have been curbed. Adaptability to new conditions is necessary for survival. Gray iron has had and will have a considerable place in our industrial economy. Its merits are not fully exploited. This does not say that the same foundries will make the same product the same old way—far from it. It indicates that as “water finds its level” so in the long run a material of construction finds that field of acceptance for which it is best adapted. The time lag or lapse can be greatly shortened by seeing to it that the story is properly and promptly told to the consuming public. The Gray Iron Division has been and will continue constructively helpful in promotion of the best interests of the castings industry. This group is relatively large, it is active. Happily it includes a number of young men along with the “old timers” in its membership. Much has been done. That which remains to be done stimulates the interest and challenges the ingenuity of all.

CAST STEEL

Industry Cooperative

Customer acceptance is a good measure of efficiency in product improvement combined with effective selling. Cast steel enjoys customer confidence. This is among factors that make it one of the powerful sinews in war production. Its gains since the last war have been based on improvement and merit. No branch of the castings industry has exceeded the steel group in its consistent and cooperative backing of foundry metallurgy.

As a purchaser's representative after the last war the writer well recalls the crude controls and procedures seen in foundries visited. Few foundries made reasonably reliable castings, as measured by today's standards. Shrinkage defects, pinholes, cracks, non-uniform hardness and other shortcomings were common.

The sound, tough, reliable steel casting of today is a result of faith in and financial backing of metallurgical advance—carefully planned, well organized, and thoroughly sold to the engineer and designer.

Soundness Important

The first essential of any metal structure is soundness. Steel is not the easiest of alloys* to cast sound. Foundrymen faced the problem realistically and searching methods of test were adopted. Quoting Melmoth⁷ “. . . there is a fear that radiographic inspection will be used as a whip to scourge the foundrymen rather than as a tool to help them. I do not believe that this is the correct mental attitude to take, and I am perfectly sure that *if we keep our minds open* we are going to use this new tool with very great advantage to ourselves.” (Italics by writer.) Although this method was brought before the Association⁸ in 1925 some of its recent advance must be credited to the Association's Steel Division Committee and to the leadership of C. W. Briggs.

A paper⁹ by Briggs and Gezelius may be credited with giving great impetus to the thorough study of the relationships of gating and design to production of sound castings. The interrelated questions of directional solidification, center-line shrinkage, contraction stresses, fluidity, design factors, use of chaplets and chills, atmospheric pressure risers etc. are well covered in recent Transactions; in the last five years we find Briggs, Brinson, Donaldson, Duma, Gezelius, Gregg, Kron, Lorig, Rominski and Taylor among A.F.A. contributors. Significantly a considerable proportion of this work has been sponsored by the U. S. Navy Department.

Composition, Time and Temperature

In matters of usage of alloys and in control through heat treatment, the steel casting industry owes much to the wrought steel industry, particularly in the earlier stages of these developments.

A fundamental development (or perhaps more accurately a method of clarification of the relationships of composition, time and temperature to end product) of recent years is the S curve of Davenport and Bain¹⁰, who are primarily wrought steel workers. They state “. . . this study proposes the addition of the time factor to the iron-carbon diagram.” The general idea of time as a fac-

* Our so-called foundry metals are in fact alloys. Even when we speak of “pure metals” in the foundry, some small additions are made to effect deoxidation, promote fluidity, and the like.

⁷ TRANSACTIONS, American Foundrymen's Association, vol. 46 (1938), p. 294.

⁸ St. John, Ancel, *X-rays in the Foundry*. TRANSACTIONS, American Foundrymen's Association, vol. 32 Pt. 1 (1924), pp. 693-702.

⁹ Briggs, C. W., and Gezelius, R. A., *Studies of Solidification and Contraction and Their Relation to the Formation of Hot Tears in Steel Castings*. TRANSACTIONS, American Foundrymen's Association, vol. 41 (1933), pp. 395-424.

¹⁰ Davenport, E. S., and Bain, E. C., *Transformation of Austenite at Constant Subcritical Temperatures*. TRANSACTIONS, A.I.M.E., Steel Division (1930), p. 118.

tor is not new, but the quantitative evaluation of time for given reactions or degree of reaction is of greatest significance to the metallurgist. Effects of alloys and of various thermal treatments become more clear. The approach is not confined to the austenite to ferrite-carbide reaction, for it can be and has been applied to other reactions. It is not evident whether the cast steel group has as yet made much direct use of this fundamental development. Certainly more economical usage of alloys (as in the N.E. steels), and studies of possibilities in treatment (as by the methods of the S curve and end quench hardness tests) constitute an attractive field for the cast steel worker.

Heat Treatment

Earlier heat treatments employed annealing to relieve internal stresses, improve machinability, get good ductility, and like properties. Today normalizing (air quenching) and drawing are widely used to enhance physical properties, and to attain maximum benefit from alloy additions. Liquid quenches are coming into greater use even on castings weighing up to ten tons. It seems logical to expect considerable extension of the method so that maximum mechanical properties can be attained wherever needed. Extension of practice of delayed quench is a probable development.

It is interesting to note that emergency development of the N.E. steels has done much to offset inertia on the one hand, and "overselling" on the other in wrought steels. This has resulted both in greater economy and in better understanding of the role of alloys.

The use of copper as an "age hardening" addition is of interest to makers of steels, malleable, and gray irons.

Physical Chemistry—Deoxidation

Researches into the physical chemistry of steel making have been profitable. Present and future findings may minimize some of the differences attributed to various melting processes. The recent work of Sims and Dahle (Proc. A.S.T.M.—1942) lends credence to that belief. Study of deoxidation processes has resulted in a number of changes; for examples, boil, recarburization and deoxidation are common practice in the acid electric furnace, whereas some years ago rather complete boil and recarburization were considered unorthodox. Considerable further development

along the lines of deoxidation, scavengers, grain size control, hardenability et cetera of cast steels, as influenced by the processes and treatment in melting, is expected. Papers like that of Sims and Dahle¹¹ and of Gagnebin¹² together with their bibliographies and the discussions, and the reviews in the 1939 Transactions possess not alone immediate practical value, but are stimuli toward further work.

Other Progress

Sand control, study of internal stresses, mass effects, and other factors are receiving the attention of the industry. Developments of molding media other than sand, and of methods, such as centrifugal casting, are significant. Lighter weight casting of more intricate design and better surface finish are more common.

Castings Applied at Elevated Temperatures

The writer's particular interest in cast steel manufacture is the production of pressure castings for elevated temperature usage. Beside pressure tightness the usage necessitates control of properties perhaps not so necessary in other applications. Some work by H. E. Montgomery and J. Urban of The Lunkenheim Company research staff illustrates approaches to achieve understanding of the relationship of elevated temperature properties to structure.

Elevated temperatures and high pressures are a severe combination, and the satisfactory service given by cast steel valves is evidence of their reliability. At temperatures of 950°F. the metal is a dull red, quite distinct in the dark. In some plants up to about 2500 lb. steam pressure is carried at temperatures 900 to 925°F. (In oil refineries considerably higher temperatures are not uncommon, but length of expected service life is not as great.)

Creep or "Flow"

Load carrying capacity drops off at elevated temperatures, as may be seen from the short time test chart, Fig. 2. Such short time or regular tensile test at elevated temperatures is misleading because when load is sustained for a long time, the phenomenon of "creep" or "flow" occurs. Beside the immediate and rapid ex-

¹¹ Sims, C. E., and Dahle, F. B., *Effect of Aluminum on the Properties of Medium Carbon Cast Steel*. TRANSACTIONS, American Foundrymen's Association, vol. 46 (1938), pp. 65-104.

¹² Gagnebin, A. P., *The Effect of Deoxidation Treatments on the Ductility of Cast Steel*. TRANSACTIONS, American Foundrymen's Association, vol. 46 (1938), pp. 132-155.

tension occurring when load is applied, the material may continue to stretch, although at a very slow rate, for many thousands of hours. It is essential that this rate be known and controlled so that the article or mechanism will not distort sufficiently to become inoperative or even to rupture. Rates of extension under one per cent per 100,000 hours are required. Suitable steel structure and suitable design stresses must be combined to achieve this result. A rate of one per cent per 100,000 hours is a rate of 0.000,000,1-inch per inch per hour, or one tenth of a millionth of an inch per inch per hour.

Creep, "Grain Size," and Carbide Distribution

It has been known to metallurgists that "grain size" has an

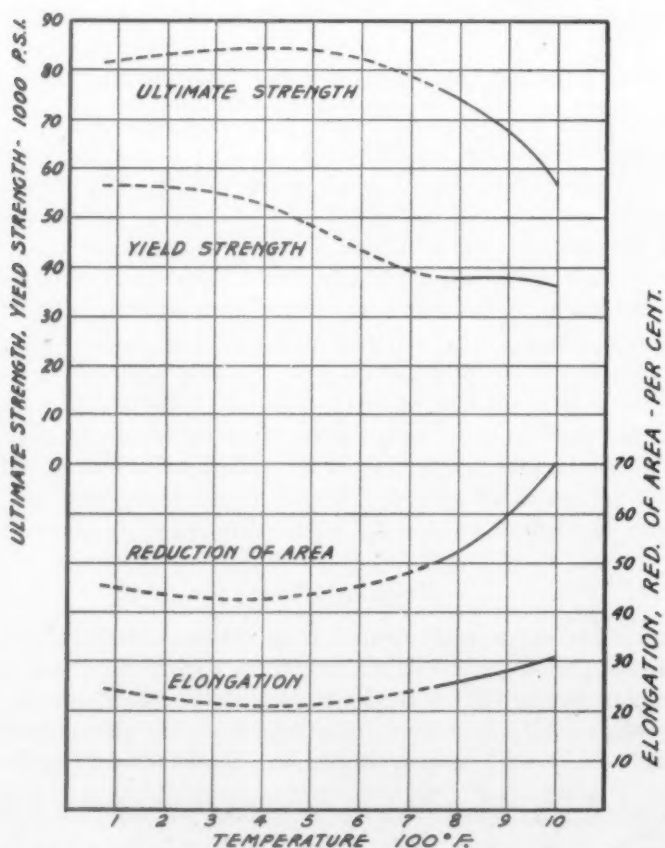


FIG. 2—EFFECT OF TEMPERATURES ON CARBON-MOLYBDENUM (WC1) STEEL.

effect; this probability was suggested by Spring and Kanter¹³. More lately attention has been given¹⁴ to the condition of the carbon in wrought steels.

The work of Montgomery and Urban, evaluating *both* these factors in a cast steel, is of interest in that it shows the tremendous differences that can be attained in load carrying characteristics (creep) of steel from the same heat and with not greatly different room temperature acceptance test results.

The steel used was A.S.T.M.—A-217-WC1, welding grade of carbon-molybdenum of the analysis of Table 1.

Table 1

	Per Cent		Per Cent
Carbon	0.26	Nickel	0.08
Silicon	0.40	Chromium	0.01
Manganese	0.64	Copper	0.08
Phosphorus	0.025	Aluminum (total)	0.085
Sulphur	0.032	Aluminum (oxide)	0.026
Molybdenum	0.50		

Acid electric process, ore boil, and final aluminum addition of 2.4 lb. per ton melt was used. A conventional treatment produces tensile test properties well above the minimum requirements of the specification, together with certain other desired properties.

For purposes of their research Montgomery and Urban used various methods, including delayed quenches, and produced the structures shown in photomicrographs of Figs. 3, 4, 5 and 6. These exhibit:

- 3A and B Coarse grained acicular*, average grain size* 4-5.
- 4A and B Coarse grained pearlite-ferrite, average grain size 5.
- 5A and B Fine grained acicular, average grain size 10.
- 6A and B Fine grained pearlite-ferrite, average grain size 8.

Creep (time-extension) curves are shown on chart, Fig. 7, all at loadings of 12,000 p.s.i. and at 950°F.

¹³ Spring, L. W., and Kanter, J. J., "Long-Time" or "Flow" Tests of Carbon Steels at Various Temperatures with Particular Reference to Stresses Below the Proportional Limits. PROCEEDINGS, A.S.T.M., vol. 28 (1928), Part II, pp. 80-106.

¹⁴ White and Crocker, TRANSACTIONS, A.S.M.E. (1941) and Miller, R. F., TRANSACTIONS, A. S. M. (1942).

* By acicular is meant a transition product intermediate between pearlite-ferrite and martensite. By grain size is meant size of ferrite grains, pearlitic patches, and acicular areas, the last as outlined by change in direction of the carbide plates, using the A.S.T.M. Tentative Classification of Austenitic Grain Size in Steels as the unit of measurement.

Great Differences in Properties

The relative order of merit of structures is:

<i>Structure</i>	<i>Creep rate—500 to 20,000 hr. period in per cent per 100,000 hours</i>
Coarse acicular	1
Fine acicular	3.5
Coarse pearlite	7.5
Fine pearlite	48

This difference of 48 to 1 at a given load is tremendous. It shows how great may be the possibilities of fitting steels to their usage.

The preceding is an ultra condensation of the painstaking and accurate experimentation by Montgomery and Urban. It indicates clearly that the factors of "grain size" and "carbide form" are interdependent. It also is an excellent illustration to foundrymen of the possibilities inherent in studies of time and rates of reaction; both on structure control and the resultant mechanical properties.

Welded Assemblies Valuable

A few years ago many foundrymen were more than afraid of the competition of and from fabrication welding. In some quarters a negative and non-constructive attitude was taken. Sampson met¹⁵ the issue squarely. C. W. Briggs urged foundrymen to utilize the art of welding, stating that "there is an almost unlimited field for the application of steel castings as integral parts of composite welded structures." Recognizing that some engineers regarded aluminum deoxidized cast steels as of dubious weldability, A. J. Smith and the writer presented¹⁶ the results of some detailed researches before the Association. Aluminum deoxidized steels compare most favorably with wrought steels of similar general composition.

The welding of cast to wrought and to cast steels has been successful in the central station field, and the number of flange and

¹⁵ Sampson, J. M., *Fabrication of Cast and Rolled Steel*. TRANSACTIONS, American Foundrymen's Association, vol. 43 (1935), pp. 351-367.

¹⁶ Bolton, J. W., and Smith, A. T., *The Effect of Welding on the Structures of Some Cast and Wrought Steels*. TRANSACTIONS, American Foundrymen's Association, vol. 48 (1940), pp. 31-65.

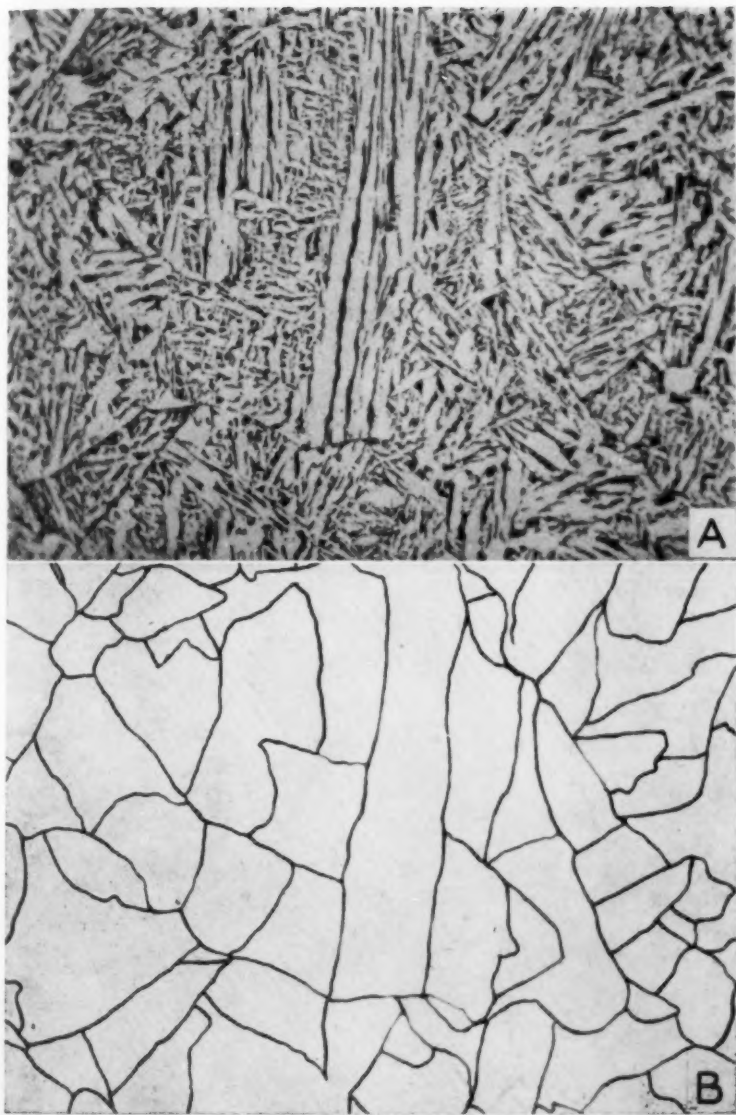


FIG. 2—(A) COARSE GRAINED, ACICULAR CAST STEEL—500 DIA., ETCHED.
(B) SKETCH SHOWING GRAIN BOUNDARIES OF PHOTOMICROGRAPH (A).

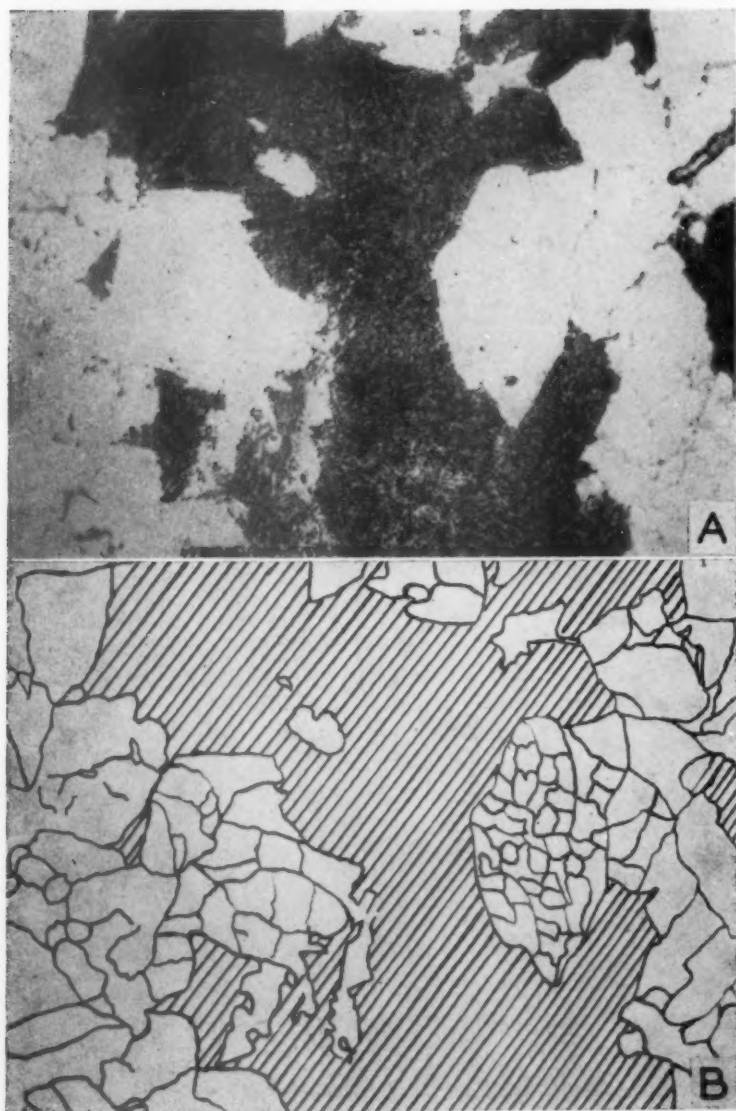


FIG. 4—(A) COARSE GRAINED, PEARLITE-FERRITE CAST STEEL—500 DIA., ETCHED.
(B) SKETCH SHOWING GRAIN BOUNDARIES OF PHOTOMICROGRAPH (A).

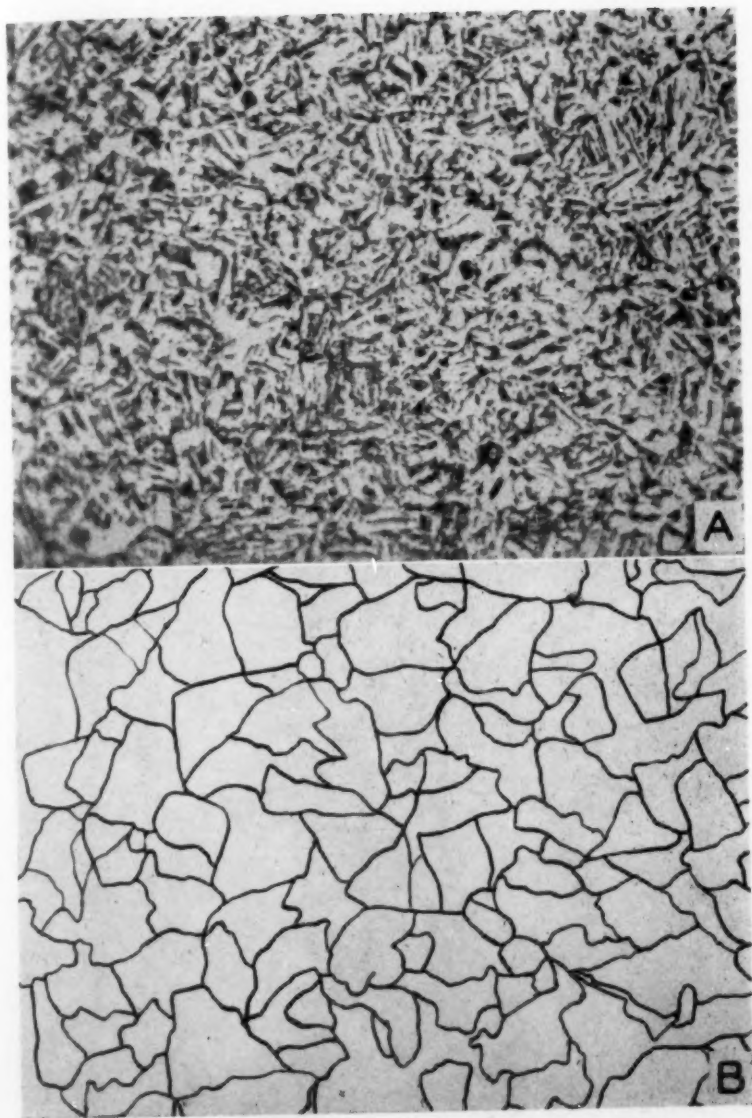


FIG. 5—(A) FINE GRAINED ACICULAR CAST STEEL—500 DIA., ETCHED.
(B) SKETCH SHOWING GRAIN BOUNDARIES OF PHOTOMICROGRAPH (A).

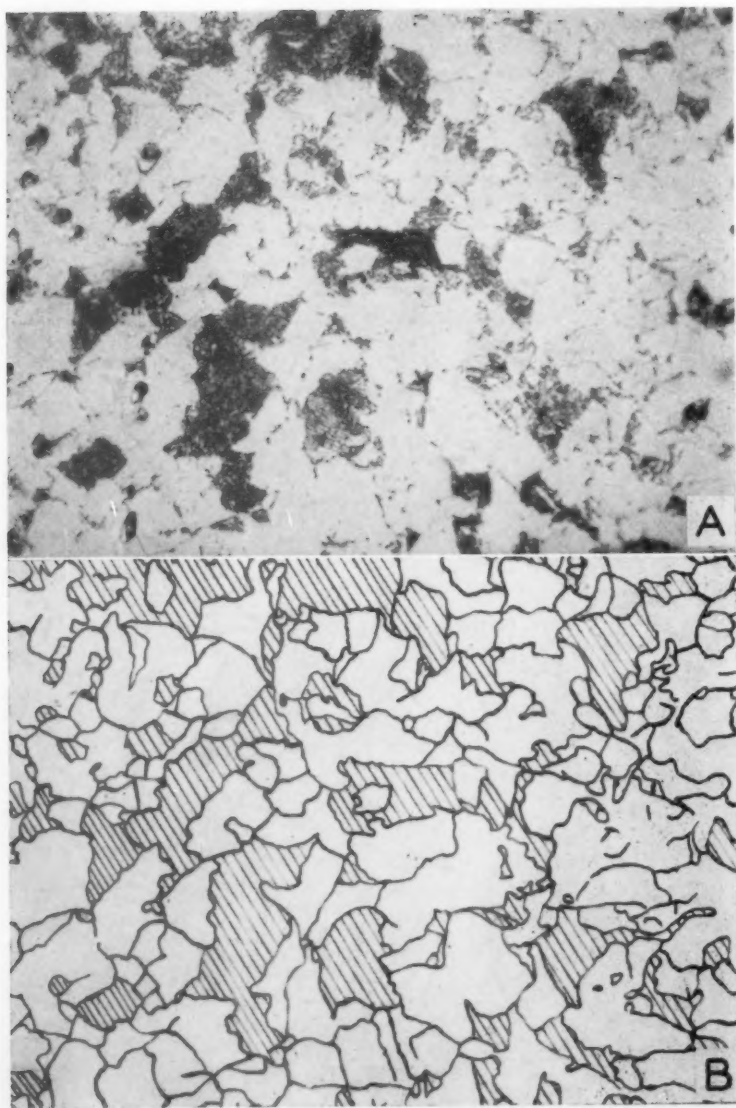


FIG. 6—(A) FINE GRAINED PEARLITE-FERRITE CAST STEEL—500 DIA., ETCHED.
(B) SKETCH SHOWING GRAIN BOUNDARIES OF PHOTOMICROGRAPH (A).

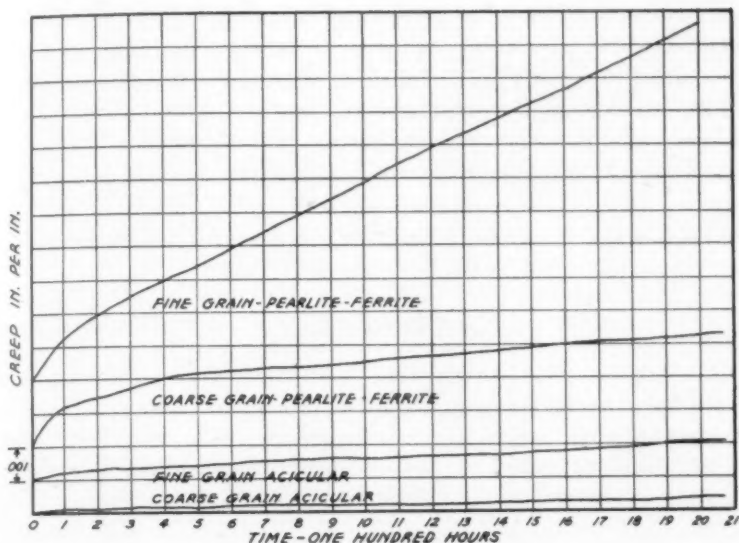


FIG. 7—CAST CARBON-MOLYBDENUM STEEL—12,000 P.S.I. AT 950°F.

bolted joints has diminished greatly. It is hoped that the steel branch of the castings industry will pursue aggressively the matter of educating designers to be fully cognizant of the possibilities of cast steel in welded assemblies.

What Will the Future Bring?

For the future we expect to see more selection of processes, primarily on basis of cost. Developments which enable substantially the same mechanical qualities to be attained, irrespective of process, appear to be on the way. More detailed understanding of depth of hardening characteristics and the factors which influence it is needed. There is a need for studies which show more definitely just how stresses are distributed. These would enable metal to be placed where it is needed as well as where it is merely wanted. The classic mechanics have their limits and involve many assumptions and deductions.

Induction melting, now applied principally to highly special alloys, may be extended along new lines, as the converter processes in turn may gain in others. Unit structural assemblies incorporating castings undoubtedly will become even more common, especially if cooperation with designers is extended.

Methods of localized hardening and deposited overlays of special metals have a good start. Sand as a molding medium has been augmented by other media. Indeed metallurgical thought has gone beyond steel as an iron and carbon alloy and contemplates alloys of iron with other elements playing the role of carbon.

The combined ingenuity of the designer, the science and art of founder and metallurgist, and the skill and judgment of industrial management, are far from their possible attainment, not alone in steel castings, but in the whole casting industry.

MALLEABLE IRON

One summer about thirty years ago, the writer was busily engaged in a malleable shop chipping room when not occupied in shaking out hot castings. Perhaps memories of the sixty hour week at ten cents an hour did not encourage a return to this field. Ensuing comments perforce must be those of an observer.

American blackheart malleable was invented by Seth Boyden in 1826. The art is a new one in comparison to gray iron and bronze casting, an old one in comparison to the casting of light alloys. Malleable iron was developed to combine fluidity, a characteristic of cast iron, and ductility, a characteristic of steel.

Founders were forced to develop technical control to attain uniformity. When bad, since it was first a product of the empirical art, malleable iron often was completely unusable—brittle and unmachinable.

Specifications Promote Confidence

Touceda was among those who promoted manufacture and sale according to definite physical specifications. Guarantees of minimum tensility and ductility are reassuring to the engineer and designer. Much also was done to standardize manufacturing procedures. For years, one trade group has promoted its product as "Certified Malleable." The industry as a whole follows specifications such as those of the A.S.T.M.

Pearlitic Malleable

There are dangers in rigid standards. It is possible that desire to maintain the *status quo* at first deterred most rapid development and acceptance of variants from the original ferrite-graphite metal. There are many possible variants.

It is not easy to promote customer acceptance effectively until there is definite classification. At first this preferably might include a relatively few clear-cut classes. Many consumers (like some manufacturers) are hesitant about adopting any but simple and clear-cut innovations. Pearlitic malleables compete not so much with ferritic malleables (hence within the industry) as with other materials of construction.

It is evident that the Association is well aware of the developments in classes of malleable iron. In fact the A.F.A. Exchange paper by Carl Joseph before the 1942 meeting of the Institute of British Foundrymen dealt wholly with one of the new modifications.

Quick Anneals

Annealing practices for malleable iron, worked out over many years, are reliable but time consuming. There seemed initially some inertia toward development of "quick anneals." Newer types of equipment and more precise knowledge of graphitization rate possibilities combine to make "quick anneals" attainable. At present choice seems to rest on economic grounds. With satisfactory product attainable by either the "long" or "quick" methods, relative cost of equipment, its operation and its control, must be balanced against value of elapsed time.

Cupola Malleable

Older specifications assigned cupola malleable to a low estate. The late L. W. Spring was among those who showed that cupola malleable possesses easier machining and better casting characteristics, together with its obviously lower melting cost. Developments and improvements in cupola melting and control are reflected in possibilities of somewhat improved metal. Greater latitude in applications is being sought.

Graphitization Problem

As with gray iron, graphitization is a major problem in the foundry metallurgy of malleable iron. There are several distinctions. In malleable the graphite is formed from the white iron structure, not during the cooling from the melt. A much narrower range of composition is adhered to, also a more limited range of casting sizes. By comparison the structural metallurgy of gray

iron is the more intricate. On the other hand the malleable industry has gone more intensively into the study of effects of time and temperature. Among those who have presented the fruits of their studies on graphitization before this Association are Schwartz, Bean, Davenport, Touceda, White, Archer, Hayes, Smith, Lorig, Forbes, Schneidewind, Boegehold, Joseph and Ziegler. The 1942 symposium held under the joint sponsorship of the A.F.A. and A.S.T.M. is an excellent summary, not alone of today's status relative to the theory and mechanics of graphitization (as referred to previously) but also of the means and procedures used to attain the desired ends.

Despite the work already done and the considerable clarification achieved, a number of problems remain. Time or reaction rate and possibilities of marked modification thereof not only attract the theorist but are of potential economic significance. Temperature and compositions are controlling media. Acquiring more precise knowledge may result in new avenues of approach toward economy, together with more complex compositions and methods of treatment appreciably different than those employed today. This industry seems fully cognizant of the usefulness of foundry metallurgy. Therefore, there is expectation rather than mere hope of progress. Expansion of usage of malleable iron product in today's war effort intensifies this belief.

NON-FERROUS (*Except Light Alloys*)

It is probable that this war period will initiate a renaissance in the cast non-ferrous field. This branch is readjusting itself rapidly to the new conditions and is playing an effective part in helping in prosecution of the war. "Necessity is the mother of invention," and acute shortages in some strategic materials represent necessity. Iconoclasm supplants tradition. Thus the story of metallurgical development can be told better after the victory is accomplished.

This branch of the foundry industry has been represented within the last twenty years by several distinguished A.F.A. presidents, namely Dr. G. H. Clamer, N. K. B. Patch and James L. Wick, Jr. Looking back over the Transactions during the period 1920-1929 one finds the names of a number of able workers who still are active, including Binney, Ellis, Roast, Romanoff, St. John, Wolf and others. Since that time the publications of a number of other aggressive workers have been added to the Transactions.

Although the number of non-ferrous foundries nearly equaled that of the iron foundries*, casting production was about one-seventh that of the gray iron foundries. There are comparatively few large units, and production of the average foundry is low.

The Transactions are not a particularly comprehensive repository of fundamental development data in this field. In fact there is, comparatively, not a great deal of data published in any medium.

There are in the Transactions a number of references to new methods of melting (high frequency induction, indirect arc, cupola, and so on) and to various "practical" aspects of foundry practice and testing. There have been, in the last twenty years, only a scant half dozen original papers dealing with the structure and chemistry of the alloys. The Recommended Practices and Cast Metals Handbook contain useful data and suggestions. They are not designed nor intended to deal with fundamental structural metallurgy.

It seems probable that the work of the Non-Ferrous Division will be expanded in the future. Review indicates that in the past, two factors have had an inhibiting action upon its activities. These are (1) the great, and, until recently, unclassified variety of alloys and (2) the organizational setups in the non-ferrous field.

Many Alloys

Five bases (copper, nickel, zinc, lead and tin) are listed by the Non-Ferrous Division. The A.F.A. Cast Metals Handbook (following A.S.T.M.-B-119) gives twenty-three generic classes of copper base alloys alone. Each class usually has several specific alloys thereunder. Each alloy may have several variations. (85-5-5-5 was said to have had 40 recognized variations.)

An appreciable degree of simplification was initiated through the efforts of Clamer and others. The WPB Conservation and Specification Division has been prosecuting simplification recently. Yet wide diversity remains. Many alloys differ, both in composition and in metallographic structure as, for example, copper-tin, copper-zinc, copper-silicon, copper-aluminum, and many varieties and modifications thereof. A result of this diversity is a comparative dearth of intensive studies and the existence of relatively few research papers. A review of actual development of each class

* Pentons Foundry List (Cleveland) 1940.

of alloy, and an organized summary of scientific and technologic advance would be difficult; a balanced one almost impossible. Many of the alloys are based on empirical formulae handed down for many generations. There remains much to be learned about a number of alloys, the standard as well as the proprietary.

Many of the copper base alloys have been handed down for generations. However, there are some relatively recent ones—certain new silicon hardened alloys being among them*. (Some other silicon hardened alloys date back many years.) The practical and controlled hardening of nickel with silicon, aluminum, beryllium, etc. has come about largely within the last twenty years. (This was one of the outgrowths of the theory of precipitation hardening.) There have been a number of other developments, such as those in the lead base alloys, within recent years**.

Organizations For Non-Ferrous Foundrymen

The American Brass Founders' Association was established in 1907. This dealt with both the "practical" and the "theoretical" fields. Meetings were held at the time and place of the American Foundrymen's Association meetings. The name was changed to the American Institute of Metals in 1912. At that time increased emphasis was laid on "theoretical" papers, and it was difficult to get "practical" papers.

In 1918 the American Institute of Metals became affiliated with the American Institute of Mining and Metallurgical Engineers as its Institute of Metals Division. Until 1927 the Institute of Metals Division continued to hold one meeting in conjunction with the A.F.A. convention.

Since that time (1927) the Institute's meetings have been held elsewhere. For a number of years its fall meeting has been held in conjunction with the American Society for Metals. Out of sixty

* The A.S.T.M. Bulletin Dec. 1942 pp. 31-35 contains a bibliography covering the literature and patent citations on silicon bronzes over the period 1926-1941, sponsored by Committee B-5. This was prepared by A. Wuest.

** Perhaps it is well to mention that your lecturer's experience in this field is limited in several respects. Some five years with "Daddy" Ling (teacher of Charles Vickers) on machine tool and paper mill castings (bearings, gears, blades, screws, and some other parts of 88-10-2, 80-10-10, manganese bronze and aluminum bronze) were followed by sixteen years on tin and silicon bronzes, nickel alloys, fusible metals, and the like—some thirty alloys possibly—all pressure work for severe engineering services. Therefore, he lacks practical experience on art castings, zinc and other die castings, yellow brass, "German" silver, alloys et cetera.

some papers on the Institute's 1941-1942 programs about four are of interest to foundrymen. The wrought metal interests predominate. This might be interpreted as evidence of apathy on the part of the castings interests.

The A.F.A. put its divisional plan into effect in 1929. As first chairman thereof we recall discussions relative to the part that the A.F.A. Non-Ferrous Division should play.

It is thought that it might be well now to consider the examples of other A.F.A. Divisions. These have not been hesitant about placing fundamental developments and "theory" before their members. Such papers have been well received. The interests of the "practical" man and the "theoretical" man ultimately are the same, and each has much to gain from the other.

There is room for more papers on cast non-ferrous alloys before the Institute of Metals.

Some excellent work is being sponsored by The American Society for Testing Materials and by some trade bodies, notably the Non-Ferrous Ingot Metals Institute. Extension of the cooperation already existing between these groups, the Institute of Metals and the A.F.A. would be helpful. The question of test bars is one among several problems that need intensive study. The old Institute of Metals was working¹⁷ on the test bar problem back in 1916. Lately Committee B-5 of A.S.T.M. assembled some interesting data which indicate the inadequacy of some conventional bars. The 1942 A.F.A. Non-Ferrous Round Table includes discussions on this problem. The following is a quotation from a resolution passed at that meeting—"Resolved, that the sense of the meeting is that test bars other than those prescribed in Federal Specifications and A.S.T.M. Specifications should be permitted and recognized when supporting data are available and given which shows that such bars produce sound castings suitable for specification and certification."

Another possibility is closer connection with the A.S.T.M.-A.S.M.E. Joint Research Committee on the Effects of Temperature on the Properties of Metals. Promotion of widest safe elevated temperature application of non-ferrous alloys demands more detailed knowledge than now exists.

Consider Generic Problems

Some problems of porosity and of age hardening are considered

¹⁷ Karr, C. P., TRANSACTIONS, American Institute of Metals, vol. X, 1916.

in the balance of this section. These generic subjects, although here applied only to copper and nickel base alloys, as of interest to the Non-Ferrous Division, also should suggest some approaches interesting to all foundrymen and workers in metals.

Soundness A Fundamental Problem

Understanding of the causes and of methods useful to combat unsoundness is a problem worthy of united consideration by all branches of the metals industry, cast and wrought. In wrought products seams, cracks, preferred orientations, and similar defects are not uncommon. In castings attention is given to the matter of porosity or lack of density, although other manifestations, such as cracks, sometimes are met.

Porosity not alone unfits a part from holding fluid pressures, but also indicates a mechanically weakened structure.

Modified tin bronzes, widely used for pressure castings, are of unusual interest when study of porosity is contemplated. These alloys seem to be susceptible to nearly every sort of "evil influence" to which metals are heir—including high sensitivity toward gassing, a long freezing range, marked segregation, and other similar tendencies.

Diagnosis Important

Correct diagnosis is essential to a logical cure. Unfortunately, porosity was originally diagnosed as "oxidation." This pronouncement was made by eminent British metallurgists and by the U. S. Bureau of Standards. As a result when Woyski and Boeck¹⁸ observed that porosity might be caused by reducing atmospheres and foundry shrinkage, little attention was given to these pioneers. The idea was not absolutely new. It is known that about 1910 Clamer had used oxide addition in the ladle whenever the gates rose on the first flask poured. (This was not published.) Although Woyski and Boeck lacked indisputable analytical proof, their observations and deductions were correct. The castings industry should have been open-minded and interested enough to promote further research to confirm or deny the findings of Woyski and Boeck.

In 1929 the general mechanisms which cause intercrystalline porosity were diagnosed and various causes enumerated¹⁹. This

¹⁸ Woyski, B., and Boeck, J. W., *Gas Absorption and Oxidation of Non-Ferrous Metals*, TRANSACTIONS, A.I.M.E., vol. 68 (1922), p. 861.

¹⁹ Bolton, J. W., and Weigand, S. A., *Incipient Shrinkage in Some Non-Ferrous Metals*, TRANSACTIONS, A.I.M.E., Institute of Metals Division (1929), pp. 475-491.

work, backed up by analytical data and much shop and laboratory research, confirmed and considerably extended the observations of Woyski and Boeck.

It was shown that porosity resulting from intergranular fissures is essentially a shrinkage phenomenon. The term "incipient shrinkage" was chosen to describe it.

Armed with a correct diagnosis (based on study of the relationship between jagged shrinkage fissures and the tiny intergranular fissures often appended thereto) it was not particularly hard to understand and to demonstrate the general roles played by gating, by pouring temperatures, by design, and by furnace atmospheres. The action of minute amounts of gases rejected during solidification could be understood. The old "oxidation" theory was exploded. It was found that basic causes lay in design, gating and (in furnace practice) the presence of "reducing" not "oxidizing" gases. The use of gas analyses to actually measure and *control* atmospheres was used and advocated.

The "incipient shrinkage" diagnosis has been confirmed by twenty-five or more research papers since that time. These add considerably to our knowledge of the various and intricate mechanisms involved. Some points remain to be elucidated fully.

The recent paper²⁰ of Pearson and Baker is recommended for study. Those authors covered the action of various gases within very small ranges of composition, temperature and time, and established the co-existence of hydrogen and oxygen (within certain limits) and subsequent reaction with evolution of steam. Extension of their technique to cover many more alloys would be helpful*.

Among a number of worth while publications those of Ellis²¹ and Doughty²² are for purposes of study usefully complementary to papers of the Pearson and Baker type. (Doughty showed that alloys of 10 per cent lead and above, when oxidized, may be reactive to carbonaceous matter in cores.)

The staff of The Lunkenheimer Co. laboratory has given porosity phenomena considerable attention, from both laboratory and plant research viewpoints. Knowledge acquired has been useful in helping maintain low losses and in avoiding "epidemics."

A certain degree of oxidation usually is required to prevent undesirable reactions with atmospheres containing hydrocarbons,

²⁰ Journal Institute of Metals (London), vol. 66, Part 8 (1941), p. 231.

* Pearson and Baker's paper was reviewed in H. L. Smith, TRANSACTIONS, American Foundrymen's Association, vol. 50 (1942), pp. 490-497.

²¹ Ellis, O. W., *The Mechanism of Inverse Segregation*. TRANSACTIONS, American Foundrymen's Association, vol. 41 (1933), pp. 347-369.

²² Metals and Alloys, Oct. 1931.

hydrogen, water vapor, carbon monoxide, and similar gases. Such reactions or "poisoning with gases" are cumulative. This was noted particularly in the case of carbon monoxide. The reaction mechanisms with carbon monoxide (taking into account the work of others on solubility) may be indirect. Its intensity varies greatly according to the alloy involved.

"Oxidation" may be accomplished by atmosphere control (by analysis). "Neutral" (CO and O₂ free) products of combustion, plus handling in air (as in pouring), effect some oxidation. This can be increased by keeping a trifle on the O₂ side. Some oxide in the charge, or added to the bath, often is desirable with the higher copper alloys. The effectiveness of solid oxide incorporation appears to vary according to the method used.

As shown by Montgomery and Wuest some alloys containing only five per cent lead, melted under above cited conditions, are quite reactive to organic material, as in molding sand or elsewhere. In some cases phosphorus is not very effective as a deoxidizer in red brasses. Weigand and Wuest have demonstrated that the effectiveness of some deoxidizers is not necessarily proportional to their heats of oxide formation. The writer has shown that in some types of alloys a very decided excess of deoxidant is necessary to effect low oxygen content. (As shown by vacuum fusion analyses.) It cannot be assumed that because a trace or small amount of residual deoxidant is found by analysis, it necessarily follows that the metal is "oxide free." The law of mass action comes into play, just as has been shown by accurate test to be the case in the physical chemistry of steel making. In all probability effectiveness depends not alone on the differences in heats of formation of oxides, but also on the possibility of partition. In other words, some balance of energies in the system is involved, and heat of oxide formation is but one. Smith and the writer have shown that a minor percentage of a special addition is in some cases effective in preventing segregation and "sweat." These particular cases evidently were due to film formation effect.

Without doubt work of this type is conducted in a number of other laboratories. Little of it is published in the Transactions. In a commercial laboratory there are limitations to the amount of fundamental research conducted. Emphasis must be placed upon practical application. One goes into fundamentals only insofar as these are necessary to clarify his own particular problems. A discreet research worker soon realizes that caution must be used in

drawing broad conclusions from observations on a few alloys. There are great gaps in knowledge. Yet the fundamental problems of composition, temperature, and time are not beyond the industry and the Non-Ferrous Division. Realization that there are broad problems is desirable.

Age Hardening

In 1919 Merica, Waltenberg and Scott presented a theory of the mechanism of age hardening²³. This was and is an outstanding contribution to the science of metals, and to practical development in the non-ferrous alloys (and light alloys) field, and in other fields also.

Among alloys there are many instances where one component possesses but limited solid solubility. If this solubility is exceeded, the excess component (called the solute) strives to precipitate from the solution. The degree of solubility usually decreases with decrease in temperature, increases with increase in temperature. Thus in a system of limited solubility, the percentage of dissolved solute is greater at high temperature. Precipitation takes place when, on lowering temperature, the solubility limit at lower temperatures is exceeded. However, if cooling is rapid, there is not enough time for precipitation to take place, and a supersaturated solid solution is obtained. (Such rapid cooling is called a "solution quench.") If then this supersaturated solid solution be "aged" (which in practice usually means reheating to some moderately elevated temperature, although some alloys age at room temperature) the excess solute (precipitate) is able to free itself from solution. Such precipitation often has a hardening effect, hence the term "age hardening."^{*}

The precipitation hardening or age hardening theory suggested many possibilities of modification, improvement, and development

²³ U. S. Bureau of Standards Sci. Paper No. 347.

* The mechanism originally postulated by Merica and coworkers contemplated precipitation in some form beyond atomic dispersion, for example, molecular, colloidal or crystalline. Certain modifications of the original theory have been made. It is suggested that the lecture of Merica (Transactions, A.I.M.E.-Inst. of Metals Div. 1932) and the symposium of the A.S.M. (1940) be consulted.

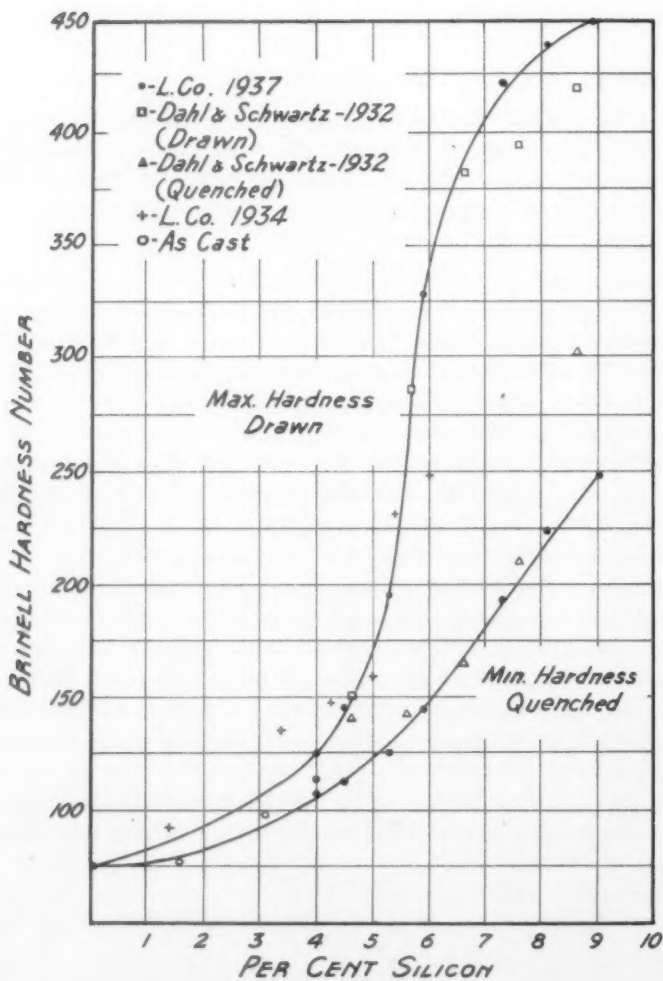


FIG. 8—EFFECT OF SILICON ON HARDNESS OF NICKEL.

of alloys by heat treatment. Conversely it brought awareness as to the probable instability (and consequent unsuitability) of some alloys, particularly for elevated temperature service.

Important as this field is practically, there are but scant references to age hardening in the Transactions—specifically three in the 1930-1940 Index. To some degree this may be due to hesitancy toward encouraging “scientific” papers in the Non-Ferrous programs. Perhaps the existence of many patents, and the numerous types of alloys involved both contribute to lack of interest on the part of foundrymen. Alloys susceptible to heat treatment can be subjected to close controls, and their properties modified to fit particular needs. Their stability and uniformity can be assured.

Hardening of “Pure” Nickel

The hardening of “pure” nickel by silicon is illustrative.

When silicon is added to “pure” nickel there is (as shown in chart, Fig. 8)* a gradual increase from 75 BHN with no silicon to about 125 BHN at 4.0 per cent silicon at “aging” temperature of 1100°F. Beyond that percentage there is a rapid increase, with increase in silicon to a maximum of 450 BHN at 9.0 per cent silicon†.

As quenched from 1800°F. (“solution treatment”) the alloy with 6 per cent silicon can be held to a machining hardness of 150 BHN with an attainable hardness of 350 BHN. (See diagram Fig. 8*.) Thus an alloy can be cast, then quenched, to a hardness at

* An early published work is that of Dahl and Schwartz (Metallwirtschaft Vol. 11, May 13, 1932 pp. 277-279). Weigand and the writer ran a series of tests covering part of the field in 1934. Later A. J. Smith ran a more complete series, using techniques markedly superior to those of earlier investigations. He was able to attain higher hardness maxima. The curves drawn are based on Smith's work. The equilibrium diagrams available seem very questionable. For example, that of Iwase and Okamoto²⁴ Sci. Repts. Tohoku Imp. Univ. 1st Series, Honda Anniversary Vol. 1936 pp. 777 indicates constant composition of 5.3 per cent silicon soluble at temperatures below 1900°F. All the results shown by Dahl and Schwartz, Weigand, Smith and the writer indicate that Iwase and Okamoto are in error. Results of age hardening studies, also creep tests cause the writer to be suspicious about many of the published equilibrium (?) diagrams on systems where limited solid solubility is involved. Not infrequently the real solubilities are much lower than indicated on the diagrams. This leads to dangers from intergranular precipitation, embrittlement, and failure.

† At approximate eutectic composition, 10 per cent silicon, the alloy has as cast some 437 BHN. This composition was so brittle that heat treatment was not tried.

which machining is conducted with ease, and subsequently drawn to a high hardness to resist wear, etc. This sequence is the opposite of that employed in hardening steel.

Nickel-copper alloys compare favorably with "pure nickel" alloys in a number of corrosive media, and are preferable in foundry manipulation. Corson recognized the hardening effect of silicon in certain high nickel-copper alloys. One base composition reactions were fairly well worked out by Bothwell and by Corson (apparently independently). Bolton and Weigand worked with the 50-50 nickel-copper base and developed the exact combinations of composition, temperature and time to insure a practical and useful result—a highly machinable alloy about 160 BHN, readily hardened to 350 BHN without any danger from cracking. Many hundreds of thousands of castings have been made under high production machining, and have given an excellent account of themselves in service.

The addition of copper to the system lowers the silicide solubility. Using 350 BHN as a relative "measuring stick," pure nickel base requires about 6 to 7 per cent silicon, 70-30 nickel-copper base approximately 4.0 per cent, 50-50 nickel-copper base approximately 2.4 per cent. In alloys with as little as 10 per cent nickel only 0.10 per cent silicon is required to produce perceptible hardening.

Other Influences of Treatment

It will be understood that with each composition a different combination of time and temperature is needed to produce optimum results. Also the substitution of a complementary base (in this case copper) has effects beside and beyond effects on hardness and on solubility—for example on ductility, strength, and the like.

The presence of a fourth element may have a marked effect on solubility. In commercial practice one does not work with metals of high purity, several elements beside the base elements and "hardener" usually are present.

For a given base there usually are several "hardeners." In the nickel-copper base alloys, silicon, tin, aluminum and beryllium are among several agents.

In some alloys advantages can be taken of the possibilities of "cumulative" action, or one can use the same agent and a different base, a means by which the writer and Smith produced up to 650 BHN in a straight silicon hardened alloy.

A shortcoming of many age hardening alloys is a tendency to

ward intergranular precipitation, embrittlement, cracking, and preferential corrosive attack. The harder nickel-silicon and nickel-copper-silicon alloys, without certain modifications, are under some conditions subject to this trouble. The writer discovered suitable inhibitors that provide immunity from such failure.

It should be mentioned that overaging can take place readily in most age hardening systems. Too high a temperature, although it may speed the reaction tremendously, also may result in failure to attain optimum properties.

Not Always Desirable

There are many cases where age hardening is not wanted. Extension of age hardening studies to our engineering alloys promotes their safe usage. Sometimes a very tiny amount of an age hardening element may cause serious impairment in properties. In some work undertaken cooperatively between Harder, Gillett, Gonser, Weigand, Milligan and the writer, it was found that a ductile 10 to 15 per cent nickel-copper alloy with manganese and iron can be completely embrittled with a few hundredths of a per cent of silicon. This embrittlement shows up after long time exposure to temperature and stress.

It has been shown that the familiar 88-10-2 bronze breaks down rapidly at temperatures in the neighborhood of 500°F. (stress present) with precipitation of the delta constituent²⁴. This reduces the ductility of the alloy and makes it unfit for engineering usage at that temperature. This finding influenced permissible temperatures in code regulations. The "M" or 88-6-4-2 alloy is far superior.

A number of new alloys have been proposed as substitutes for older bronzes. Prominent among these are the silicon bronzes and brasses. Any new alloy should be investigated carefully for aging propensities. If elevated temperature application is contemplated, such investigation should be thorough. Aging may harden and strengthen the alloy with little loss in ductility. In some alloys aging may even increase the ductility, or it may cause embrittlement. Aging studies should cover hundreds of hours of test, at temperatures slightly above contemplated temperature of operation.

In cast alloys solidification processes promote some segregation. If diffusion is not rapid, and if homogenizing treatments are not

²⁴ Bolton, J. W., PROCEEDINGS, A.S.T.M., vol. 35, Part 2 (1935), p. 204.

used, segregation persists. In such cases local precipitation or age hardening may be a result.

The practical foundrymen seeks extension of means for controlling the uniformity of his product. The engineer desires stable and uniform materials. Heat treatments permit control beyond the "as cast" structure. It is probable that in the years to come heat treated foundry alloys will be used more extensively, and possibly supplant a number of the alloys in use today. The field is relatively new, the possibilities attractive.

Summary

There remains much interesting and useful work to be done over and beyond the present good efforts of the Non-Ferrous Division. The active workers in this division have indeed given much in time and effort, and they have been objectively cooperative. Two handicaps are the great diversity of alloys and the comparatively small number of men really active in this field. There appears room for further elementary exposition of structural metallurgy in the Transactions. Beyond that there is need for correlated abstracts and summaries. More development in fundamental theory would be useful. Some ordinary everyday matters, such as designs of test bars, might well be subjects for cooperative research. There appears to be room for extension of direct cooperation with other technical societies, on projects of mutual interest. Certainly there is room for more extensive direct participation and support by a greater number from the many non-ferrous foundries.

The war has forced many and rapid changes in nearly every non-ferrous foundry. This progress doubtless will be reflected promptly in expansion of Association activities and in the advancement of this branch of the castings industry.

LIGHT ALLOYS

Tremendous war time production and usage of the light alloys (aluminum and magnesium base) have attracted the attention of the public and have increased the interest of capital and of management. The lightness of these metals, their machinability, the greatly expanded production capacity now available, and the lowering in cost per pound to the founder or other user are a combination which suggests expansion in domestic usage after the war. Producers of other metals recognize the competitive possibilities, and some are disturbed thereat. In turn, all metal producers must

needs keep a wary eye on the developments in plastics, in ceramics, in laminated wood constructions and the like.

The author has had limited practical experience in aluminum—mainly two alloys in sand castings for pressure parts—and none in magnesium. Beside this the Transactions to date are not a particularly good repository of information relative to metallurgical progress in this field. These facts make a representative and balanced review difficult.

In the case of magnesium the paucity of papers is not difficult to understand. It is stated by Brooks that magnesium alloy sand castings were introduced on a practical scale in 1929. An annual production of but a million pounds was reached in 1939. Since that time increase in production has been indeed great. An early paper²⁵ before the Association was that of Brooks and Gann followed by that²⁶ of Brooks and Winston. These useful contributions plus Recommended Practices²⁷ constitute the total. Much undoubtedly is being done in many foundries now. It is hoped that, when politic, records of these developments will find their way into the Transactions.

In the case of aluminum the period of 1920-1929 saw contributions from several sources. The paper²⁸ by Basch is a typical discussion of new developments in alloys, their handling, and their properties.

In the period 1930-1942 inclusive there have been but nine papers. Literature (elsewhere) and patents in this field have been extensive, in contrast to the paucity of original or development papers in the Transactions. We must go to Rowe and Gingerich to find a direct treatment of general problems²⁹, although here and there useful comments appear, for example, those of Gillett³⁰. Whether this situation is a result of foundrymen at large depending on research data divulged by one large and excellently equipped group is debatable. The war has brought aluminum into many foundries, and it well may bring increased catholicity and

²⁵ Gann, J. A., and Brooks, M. E., *Founding Magnesium Alloys*. TRANSACTIONS, American Foundrymen's Association, vol. 43 (1935), pp. 591-614.

²⁶ Brooks, M. E., and Winston, A. W., *Magnesium Foundry Practice*. TRANSACTIONS, American Foundrymen's Association, vol. 49 (1941), pp. 165-187.

²⁷ *Recommended Practices for Sand Cast Magnesium Alloys*. TRANSACTIONS, American Foundrymen's Association, vol. 44 (1936), pp. 33-50.

²⁸ Basch, D., and Sayre, M. F., *Foundry Treatment and Physical Properties of Silicon-Aluminum Sand Castings*. TRANSACTIONS, American Foundrymen's Association, vol. 32, Part 1 (1924), pp. 350-383.

²⁹ Rowe, H. J., and Gingerich, E. M., *Practical Foundry Considerations for Improving the Soundness of Aluminum-Alloy Castings*. TRANSACTIONS, American Foundrymen's Association, vol. 40 (1932), pp. 527-546.

³⁰ Gillett, H. W., "The Role of Silicon in Non-Ferrous Castings," TRANSACTIONS, American Foundrymen's Association, vol. 41 (1933), pp. 413-441.

many new developments. Here again the story can be better told at a later date.

A new Division, to deal specifically with the light alloys, has been organized. This closer community of interest well may lead to more extensive activity within the Association.

The alloy AN-QQ-A376-2 (formerly known as 11307-HT-2) or Alcoa 355 is listed as Alloy 1, Heat Treatment 2 in Reference Table 88 p. 299, Cast Metals Handbook. It is essentially a five per cent silicon alloy modified by other elements, and age hardening.

A minimum tensility of 32,000 lb. per sq. in. and a minimum ductility of two per cent are prescribed. Because of this alloy's lightness, the tensility, weight for weight, is somewhat better than that of the more common grades of cast steel. Two per cent elongation appears rather low*.

The AN-QQ-A376-2 alloy finds considerable usage where weight is a consideration. That this alloy and other aluminum alloys of low ductility are used successfully where stresses are far from static is a partial answer to "ductility crazy" users of metals.

Under favorable conditions a tensility of 40,000 lb. per sq. in. and an elongation of about five per cent may occur. Composition and heat treatment are controlled to very close limits. Therefore much of such variation must be attributed to other factors in foundry science and art. The spread from minimum to maximum is some twenty-five per cent in tensility and two hundred and fifty per cent in ductility. One can expect considerable spreads in some alloys used as cast, because variations in cooling rates in the mold are in themselves heat treatments. However, in heat treated alloys, cast carbon steel for example, a frequency chart will show the bulk of tensilities lie within a range of ten per cent. Following this reasoning it might seem that prescription of 38,000 minimum tensility and 3.5 per cent minimum elongation might at some time be possible with this aluminum alloy. Such improvement would be well worth while in any alloy, and enhance its competitive position relative to wrought alloys.

Let us consider what has happened in another field. Within the last twenty years specifications for the now largely proscribed 88-10-2 bronze have been raised from 30,000 lb. per sq. in. to some 40,000 lb. per sq. in. minimum. It is a poor foundry that cannot average about 48,000 lb. per sq. in. with that alloy today. Twenty

* The error in fitting test bar ends together is appreciable. A minimum ductility of two per cent may well mean an actual or true elongation of one per cent or a little over.

years ago there were those who had trouble getting 30,000 consistently. Let us say that the alloy has been improved some sixty per cent in strength. How? Simply by seeking out the causes of internal unsoundness and remedying them.

In case of the AN-QQ-A376-2 aluminum alloy a tensility of 40,000 lb. per sq. in. and 5 per cent elongation probably do not represent the ultimate. Careful examination of metal productive of good test bars sometimes shows that internal discontinuities remain. Here is one of the many challenges to the science and art of foundry metallurgy.

There is a trend in the AN-QQ-A376-2 alloy for tensility and ductility to increase simultaneously. Experience with and study of thousands of tests on other alloys indicates that when this trend occurs relative structural soundness often is involved. This occurrence in the AN-QQ-A376-2 aluminum alloy probably is of similar cause.

Freedom from leakage under a pressure test is no assurance of desirable maximum density throughout the section. Further, a casting that actually leaks is weak in the leaky section. In the literature in general there are numerous references to tendency for unsoundness in aluminum castings*.

Soundness is a primary consideration in all cast alloys. Indeed its attainment is a *sine qua non* in competition. The jibes of the wrought alloys man are directed toward the "unreliability" (?) of castings because of their "inherent" (?) unsoundness. Great strides have been made in some castings fields. Steel and bronzes produced today are far ahead of the sometimes sorry structures encountered twenty-five years ago. Nor are the wrought alloys free from defects.

What is the situation in aluminum alloys? First, it may be said that early attention to design factors and the application of X-ray study and inspection have been beneficial in minimizing possibilities of gross discontinuities or defects in castings.

Second, many usages of cast aluminum are in general not severe, particularly in pressure and temperature applications. A great many castings have been made in permanent molds and as die castings, wherein some of the problems of dispersed and minute porosity and of pinholes are minimized.

There are in existence specifications which permit the treating

* Recently it is claimed that a high pressure die casting process has enabled certain cast products to compare very favorably with wrought products.

(sealing) of aluminum castings. Where strength is no particular consideration it may be proper to indulge in such practices. However, as an easy way out, it hardly encourages developments in foundry metallurgy.

One of the evils to which some alloys are inclined is gas porosity—usually hydrogen in case of aluminum. On p. 538, Transactions, A.F.A., vol. 40, 1932, is shown a photograph of a porous ingot, and of an apparently sound casting made therefrom.

Unless means be taken to eliminate initial gas contamination it is too much to hope that ordinary foundry melting will be helpful in itself. The chances are that there will be additional contamination from products of combustion—such as water vapor from burning of hydrocarbon gases or oils, or even from the humidity of the air.

It is difficult to avoid the many sources of contamination entirely. Non-reactive gases such as nitrogen and chlorine are used to “wash” hydrogen from the molten bath. It would appear that much of the improvement resulting from such treatment is brought about by dispersion of micro-voids or pinholes. Pinholes, being discontinuous, are not (as a rule) sources of leakage on a pressure test, but their presence, even if microscopic in size, is not desirable. Continuous voids (referred to as incipient shrinkage in bronzes) if they occur, should be of more concern to the engineer.

Sachs and Van Horn (*Practical Metallurgy*—1940) show differences between “gassed” and vacuum melted metal (p. 195 Fig. 128). Those authors refer to several methods of gas removal (p. 197). In their Chapter VIII, “Castings Production,” references are made to and illustrations given of extensive usage of chills, multiple gates and the like, which of course foundrymen recognize as expedients rather than basic cures. Illustrations of practice as seen in the trade press frequently show these sometimes cumbersome and expensive (although for immediate results frequently needed) devices.

The ultimate objective is sound castings at lowest cost. Sound castings are the first essential. Aluminum foundrymen are wise in going to whatever means may be necessary to obtain them. Aluminum has no “bad name” from unserviceable castings in the field. The writer has pointed out elsewhere the grave dangers of false economy and in making things “cheap.” Yet the simpler and more economically a quality product can be made, the better the competitive position of the industry. It has been said that it is foolish to expect to pour metal into a hole in the sand and hope

to get castings of (so-called) forging quality. Perhaps so, but strange as it may seem that is just what the progressive foundry metallurgist seeks. Frills have no place in his imagination.

One is reminded of the arguments pro and con about pinhole porosity in steel some years ago. In that case somewhat better the understanding of the intricacies of reactions during the melt and evolution of preventative measures solved most of the difficulties.

There sometimes is a tendency in the casting industry for the branches to strike at what they feel may be "easy" competition in their own industry. Some years ago cast steel replaced much cast iron. Today cast steel is giving more attention to wrought steel, and malleable and gray irons are going to some degree into fields where cast and wrought steel prevailed. Perhaps in the aluminum field efforts to equal or exceed aluminum forgings on the one hand and to prevent inroads by plastics on the other would be well worth consideration. Where lightness plus strength are needed aluminum and magnesium alloys have some inherent advantages. Freedom from rust is another. Lightness, it must be remembered, is not always an advantage in all types of engineering service. Properties like damping capacity, wear resistance, freedom from galling and resistance to compressive loads often need be taken into consideration in engineering applications.

Whether certain of the more obvious peculiarities (including high heat of oxide formation) inherent in aluminum alloys preclude developments effected in some other fields or whether the art in this field is as yet somewhat behind that in other fields cannot be fairly stated. This inability to evaluate exactly is particularly evident when, as in this lecture, references are confined largely to the Transactions. If Transactions of the future contain a greater number of development records, more papers on various practices, and more extensive discussions, some possibility of better balanced review would exist.

The new A.F.A. Aluminum and Magnesium Division certainly has most interesting work before it. If the ease of getting the ultimate in dense uniform castings can be promoted, the greater strength and toughness of such product (reflected in specifications) will do much to enhance the competitive possibilities of this product. The light alloys branch after all is relatively a new one in comparison to the other branches of the castings industry. That much has been accomplished by the light alloys branch is highly commendable. Further, recognition that there may be possibilities for future improvement is necessary if progress is to be made.

SOME PRINCIPLES IN TECHNOLOGY

Development and its subsequent application are essential for advance in foundry technology. Obsolescence is a subtle poison, but a sure and deadly one. Constant and consistent research is insurance against obsolescence, and investment for the future.

In research, as in all fields, personnel is a basic problem. All ideas stem from men; execution and accomplishment rest with men. Those who have the simplicity to wonder, the courage to try, the perseverance and ingenuity to accomplish, must have backing if industry is to grow and flourish.

Research involves both *how* and *why*, often called "practice" and "theory." Immediate interest usually is in the *how*. Impatience if not scorn often are vouchsafed the *why*. True enough, the *how* often precedes the *why*, at least to outward appearances. The *how* may be empirical, it may be skill, it may even be but rule of thumb, or it may be based on a *why*.

Once a *why* is mastered and applied many *hows* almost automatically suggest themselves. We consider Newton and Pasteur great because their discoveries of some *whys* revolutionized the fields of mechanics and medicine respectively. We honor Howe and Merica because their *whys* opened veritable floodgates of practical discovery.

Planned research is more effective than haphazard experimentation. The term research has been bandied about so much in the public press that the man on the street may feel that he is conducting research if he merely looks up a definition of a word in the dictionary. Likewise the founder who occasionally modifies a gate or alters the blast volume for his cupola may consider himself a research worker. In actuality such activities are but routine alterations. Research, as it is understood by the professional man, involves exactly controlled experimentation, precise and systematically recorded observation, and an attempt to correlate cause and effect. It is neither routine nor haphazard. Planned research often includes a generous portion of the *why* or so-called theoretical research.

Industrial research men are far the better for practical operating experience. Close contact with operating conditions is both revealing and stimulating. Some actual contact with the many and varied conditions of foundry practice should be sought, even by workers in pure theory.

Research is in itself a business and a profession. It involves ex-

penditure, and return should be expected. While return may be direct, it often takes a long time. Sometimes it is intangible. In the latter case, although the results may be far reaching in ultimate economic significance, they may be very difficult to evaluate in concrete terms. Different groups of men often differ greatly in productive capacity. Usually the adage, "Genius is ninety-nine parts perspiration and one part inspiration," fits. Research sometimes is used for propaganda. Moreover propaganda sometimes masquerades as research. Research implies an objective approach—propaganda often the opposite. Research has honest advertising value, if the research is producing anything of significant worth to the customer. Yet we well know that in advertising there often is wishful thinking, not to say marked exaggeration.

Within the Transactions of the Association, intellectual honesty must perforce be prevalent. In its open forum analysis and criticism must be faced. This is a brake on possible untoward tendencies.

Application often requires considerable skill. In some research work the variables are kept to a minimum, so that basic reactions and principles can be understood. The child of the laboratory may find tough going in the foundry—it is not sheltered from the variables. Some one with understanding of both research and practice must bridge the gap. Keen power of observation and real ingenuity are needed. Proficiency in the art as well as in the science is essential. The development of instrumentation and of test methods has helped greatly in making transition into practice more sure.

When application has been worked out, technical control comes into play. The advantage gained must be maintained to assure the cycle of success. Control frequently is regarded as mere dull routine. Some of it is. Yet an alert control man actually in the foundry can be very valuable. His finger is on the patient's pulse at all times. He can observe untoward symptoms and seek means for their correction before minor troubles become major epidemics.

Foundries which conduct research directly are in the minority. Yet all foundries pay for research. In many cases those who pay most dearly are those who, without research, or even good control, have great and hidden losses. Oftentimes wastages and losses are unsuspected. Thorough checkup may reveal surprising things. Riding on the other fellow's developments is far from a safe or conservative business policy.

FOUNDRY METALLURGY, THE CASTINGS INDUSTRY, AND THE MACHINE AGE

Preceding sections refer specifically to some of the developments in the art and science of foundry metallurgy, and suggest that these are important economically in maintenance and extension of the competitive position of the castings industry. This section considers some relationships beyond matters of technology and manufacture.

The material significance of the foundry industry was beautifully defined* by the widow of Seaman medallist Jesse L. Jones, as follows:

"... the metal industry . . . is an essential, a basic industry. On its broad foundations rest all the manufactures, all the transportation, all the commerce of the world. In the heat and dirt and labor of the foundry, in the exacting and tedious toil of the laboratory, may you never forget the intrinsic value of your work. The strength and reliability of the iron, steel and aluminum, the copper, brass and bronze, which you produce, determine the safety and success of our whole modern industrial life. The progress of this great mechanical age waits your research. I believe it was because my husband so clearly visioned this, that he loved his work, and because he loved it he attained success in it."

The castings industry is but a cog within the huge industrial machine. Foundry metallurgy is but one factor in the castings industry. The machine has altered the life of man—his food, his clothing, his housing, his transportation, his communication—it is the medium through which products of mine and farm and forest—from land and sea and air—are made available. Failure to integrate practices in political economy with the developments of the machine age has resulted in a paradox. The machine age brought and brings potentiality for peace and prosperity beyond that ever known. We have war, death, suffering, hunger and waste. We hate, we curse this paradox of misery and want co-existent with potentiality for happiness and prosperity.

The enemy has evoked the beasts' law of claw and fang, more effective, more deadly, through application of the machine. Our confidence in victory is based not alone on the bravery of our boys, and the skill of their leaders, but also on our greater proficiency in the evolution, production, and application of the machine.

* TRANSACTIONS, American Foundrymen's Association, vol. 37 (1929), p. xxxii.

The castings industry has played and is playing an important part in the war effort. If courage and vision be evoked, it can and will play an important part in the era of peace.

Will those who have won the victory over tyranny be content with regimentation? Will you who have played a part in creation of the machine continue to remain content with the paradox?

War is a great stimulus to technical achievement. May not an added by-product be a greater social consciousness within us, and in the affairs of the Association?

Is business run for profit alone? Is not the real end service, social service, if you please? An immediate objective of foundry metallurgy is the evolution of a better and less costly product. Exploitation of such a product aids the casting industry to maintain and improve its competitive position. Alloys which are safer, more useful, and more economical materials of construction are an objective. And the machine of which the material is a part has as its reason for being that it saves the labor of men, and promotes their safety and material happiness. Can we then evaluate castings only on a price per pound basis? Shall we merely grub blindly amid sand and hot metal? Cannot we take pride in our calling and seek understanding and respect from our fellow men?

Quoting Steinebach*. "Today the war effort and the foundry industry suffer from lack of united action on foundry problems. Both government and industry are at fault."

Whether it be war or peace, united action is necessary. Courage and vision are needed for unity within our industry and in our Association. Beyond these, unity is needed in industry in general, and integration of all with the affairs of government.

PLANNED METALLURGICAL PROGRESS

Education and the promotion of research and development are recognized functions of the Association. The A.F.A. has been a leader in encouragement, organization, and publication of research and information in the field of foundry metallurgy. These accomplishments are reflected in improved products and practices. It is desirable that such accomplishments be not only continued but also expanded. Careful planning is necessary to assure this.

There are things that are wise to do, other things that are important to avoid. Many able men have supported the Association within its forty-seven years of existence. We see the things that

* THE FOUNDRY, vol. 71, No. 1 (1943), p. 65.

they have done. We rarely see the things that they carefully avoided doing. The last perhaps have been equally important toward success.

Numerous specific problems are dealt with in Association work. There also are many generic problems in foundry metallurgy. Usually such work, on generic problems, can be done best by a group or groups representative of the whole industry. It is rare that a single firm can go as far as might be desirable in fundamental problems, problems that concern the industry as a whole. Here lies a field for further extension of Association effort.

Progress within and by the Association has been a product of cooperative effort. Some of this accomplishment has been a result of long range planning. Some perhaps "just grew." In considering perpetuation and expansion of technical advance let us always remember that cooperative effort has been the foundation and mainspring of progress. Encouragement of more concerted approach on generic problems is desirable. Any regimentation is to be most carefully avoided. Individual and competitive effort is the life of research as well as of trade.

In total or partial sponsorship of a research project by the Association there are concurrent dangers. One is impatience by members with any beside immediately applicable results and with so-called theoretical research.

A difference between theoretical research and applied research is one of temporary objective. In "theoretical" research knowledge is sought, in the hope and expectation that it will serve as a broad foundation for many applications. In applied research a more specific and limited objective, the solution of one particular problem, is pursued. Not infrequently applied research may lead indirectly to the development of theory, particularly if properly directed.

Some may take the attitude that the Association should do their research for them. Valuable though the work of the Association is, it does not take the place of nor does it compete with privately sponsored work. President Forbes says* "Although the foundry industry is fifth in size in the United States, it is nowhere near that in point of the amount of attention it gives to study and research." The Association can not in itself bridge that gap.

Committee work has been a fertile source of progress in the Association. Joint efforts plus individual publications represent not alone good will but also research expenditures that run not

* AMERICAN FOUNDRYMAN, vol. 5, No. 1, Jan. 1943, p. 2.

into the tens, but into the hundreds of thousands of dollars. The Association has and will promote logical and coordinated extension of committee work. Among the ways in which the Association has done and can do much to promote the well-being of the industry are:

(1) Making accessible the results of work already done. Moldenke many years ago wrote* "The transactions of the foundrymen's associations and the great iron trade journals are still the repositories of this growing fund of information, which nevertheless requires discriminating study to separate the kernel from the chaff."

Today the problem is multiplied many fold. This is not alone because of the many media. Correlated and critical abstracts and symposia are needed and are of great value.

(2) Help meet the need for elementary and clear-cut expositions both on "theory" and on "practice," useful both to the beginner and to refresh the older man's knowledge.

(3) Sponsoring or aiding research and development. Among possible approaches are:

(a) With its own staff and equipment.

(b) By grants to its committee for pursuit of approved problems.

(c) Through hiring the services and facilities of universities, research institutes, consultant, establishing fellowships, and other agencies.

(d) In cooperation with agencies, such as other technical and governmental bodies.

Whatever approach or combination of approaches be chosen, consistent plan and concerted action are essential. Mere enthusiasm is no substitute for analytical judgment and for vigorous and economical prosecution.

An objective of research is the maintenance and improvement of the competitive position of the industry. The actual work may concern such items as:

(a) The raw materials used, directly and indirectly.

(b) The product. castings. This includes such factors as mechanical properties, use of alloys and study of design.

(c) The processes—for example, melting and molding.

(d) Applications and uses of products—one of the at present weakest links in the foundry structure—as long as thought is centered on price per pound.

(e) Fundamental principles and theory.

* Moldenke, R., Principles of Iron Founding, McGraw-Hill Co., New York.

(4) Promoting justifiable extension of usage of cast products.

(a) Publications such as the Cast Metals Handbook provide "current and authoritative information as an aid to the engineer dealing with the many products of the foundry." This has been and should be a product of committees. However, somewhat more thought might be given the achievement of a consistent plan.

(b) Symposia in cooperation with consumer-producer groups, the American Society for Testing Materials being a group so recognized.

(c) Cooperation with code and specification making bodies. Not infrequently the foundryman has little or nothing to say about codes—some restrictive—which define the applications of cast product. Among groups are those of governmental agencies and of consumer bodies.

(d) Joint effort with other producer groups—say as with the American Welding Society in matters of cast-weld products.

(e) Thorough correction of handbooks and published metallurgical data, which often are out of date or misleading. Should the gray iron man smile or swear when he reads in a recent reference book that "Cast iron is brittle . . . Tensile strengths vary from 18,000 to 26,000 p.s.i. . . . Semi-steel . . . High test cast iron . . . A term for cast iron that has been superheated in the melting for pouring and then the castings given a treatment to prevent chill in order to produce a tough white iron"? The fault is not fully with the authors and publishers.

(f) Encouragement of and constructive help for writers of papers and articles, as in the Transactions and the American Foundryman.

(g) Furnishing of many descriptions of successful service applications, and finding out causes of unsatisfactory performance, and getting these before the designer and engineer, the foundryman, and the metallurgist.

(h) Arousing foundrymen toward greater confidence in the ultimate value of their product, and to greater knowledge of its usages—in short to promote constructive "sales-mindedness," on basis of merit in use rather than on basis of first cost to the customer.

(i) Aid to schools in getting the story of castings properly before their students, and in the selection of courses fitted to training foundry workers.

Many other approaches might be mentioned. Too often we think of gray iron, malleable, steel, non-ferrous, and the light alloys as separate and distinct fields. They are not. Composition, time, and temperature are fundamentals. Differences between alloys are in degree rather than in kind. Basic principles are alike. Useful analogies are common, even if too infrequently perceived.

Management is acutely aware that functionalization has produced the operator in contrast to the craftsman. Specialization also may produce the non-ferrous technician, the iron expert, and so on rather than the all round metallurgist. Restricted function, specialization, has a useful place, but it has its dangers. Intensive work may well be directed to a specific alloy, but the question of adaptability of the findings to other alloys is ever to be borne in mind. This is especially so in Association work.

The Association has established a Foundation. In the initial resolutions, "consistent plan and concerted action" were emphasized as guiding principles. Provision was made for skilled and able leadership. It is understood that the Foundation's work would be supplementary to that of existing agencies within the Association. Further, the Foundation is intended to help and facilitate the working and perpetuation of existing activities, not to supplant them. While there is room for a more consistent plan and greater concerted action in any organization these must be achieved by cooperation. The American Foundrymen's Association has grown strong because of the good will and freedom of action among members. Any hint of regimentation would destroy invaluable initiative.

To build soundly for the future is an objective of the Association. The establishment of the Foundation can well be another valuable step in that direction, and of material aid in the carrying on of and in extension of the activities of the Association.

SUMMARY

During the past 20 or 25 years many changes have occurred in the foundry industry. In an endeavor to outline the trends, more particularly of foundry metallurgy, the author, beside or beyond compiling a review, has presented brief expositions of some unpublished research and mentioned problems which merit further study. While the Association has played an important role in the advancement of foundry metallurgy, suggestions are made on how it might promote further development and advance. Those include a seeking of a broader viewpoint toward technical advance and attaining a greater social consciousness by both industry and individual.

The aluminum castings industry was just coming into commercial being some twenty-five years ago. Practical casting of magnesium alloys was undeveloped. Cast steel of controlled qual-

ity, as we know it today, was rare. Accurate understanding of the influence of temperature under the pearlitic interval was among things lacking in the malleable field. With but few exceptions gray iron was judged more on basis of weight and machinability, than on basis of strength and true suitability for the service. Non-ferrous alloys were made, by and large, to traditional formulae and by empirical methods. In all fields there has been advancement in quality of castings and in methods of manufacture.

Development of scientific methods of control and research, and the applications of these to foundry work have been numerous. Twenty-five years ago a simple direct combustion method of determining carbon content of cast iron and steel was quite new. Practical pyrometry in foundries was in an early stage. Measured control of sands was not practiced. Radiography as applied to commercial castings seemed far-fetched. "Creep" testing was undeveloped and practically unknown. The metallurgical microscope was, in the castings field, a scientific toy rather than a practical tool. Use of the electric furnace was just starting. Usages of "alloys" in cast irons were rare. Heat treatments in most shops were, by and large, crude. Age hardening was barely known and not at all understood. Many more examples might be given.

It is during this period that the automobile industry became huge. This in turn promoted expansion in oil and other industries. Chemical industries also were greatly expanded, following the breaking down of the German monopoly. Agriculture was more mechanized. These and many other developments necessitated the usage of large amounts of metals—including cast metals. There were needs and demands for greater strength, less weight, more resistance to corrosion, better wearing properties, improved dynamic characteristics, greater stability and reliability when exposed to higher temperatures and stresses, and so forth.

The castings industry has been markedly influenced by general manufacturing progress. It has, to an appreciable degree, taken advantage of developments in scientific metallurgy and in the newer methods of measurement, instrumentation and control. There have been many advances in mechanical handling and working in the foundry—in transportation of materials, in cleaning, in machine molding, and the like. Some branches have taken extensive advantage of these developments. In the author's opinion the greater number of foundry managements have paid more attention to advanced mechanization than to possibilities within the extension and application of metallurgical science.

This war is having a tremendous effect on the metals industries. Stern necessity has smashed complacency to shreds. A more fluid, a more mobile attitude is likely in the bitter post-war competition. War throws old practices out of their old grooves and channels. Clear thinking and swift action are needed in war against the common enemy. They will be needed no less by industries in the post-war reconstruction.

D. J. Reese stated* "If the base metal was designed for alloying, these same foundries would require about half as much alloy—it means that they require three and four and five pounds of alloy to do the job that one pound of alloy could do." The preceding quotation suggests that lack of metallurgical knowledge always has been paid for by the founder and dearly so. It infers that the easy way out, trying to get something for nothing, not only has cost the founder and the consuming public a pretty penny in normal times, but also may lead to the squandering of strategic resources in war.

The castings industry undoubtedly has been (as suggested by Reese) wasteful in usages of materials. A lesson of this war is that as a nation we have been indeed foolishly wasteful in many ways. There are far worse examples of wastage elsewhere than those examples found in the castings industry.

We have, in the American Foundrymen's Association, a group "to promote the arts and sciences applicable to metals castings manufacture—"† The Association is an educational and technical society for the whole castings industry. Men from different and often competing foundries have found that it is of great value to trade ideas and help each other. Perhaps it is not equally clear to the branches of the industry that they too have much in common, and that much remains to be done in the matter of concerted attack on the educational and technical problems shared by all.

Review of technical advance teaches clearly that rate of progress is accelerative. The Association well may have just pride in its accomplishments. Yet all should remember that even more swift progress is needed to meet the challenges of the future. And what is the Association? It is a group of individuals. Since it is composed of individuals, the Association advances in proportion to the degree that individuals support it actively, personally and financially. Conversely the Association will retrogress if indi-

* THE FOUNDRY, vol. 71, No. 3, Mar. 1943, p. 81.

† American Foundrymen's Association By-Laws, Art. 1, sec. 2.

viduals regard it as a mutual admiration society, pay for nominal membership, and let direct interest lag.

It has been a great privilege to be permitted to prepare and deliver this Lecture. If younger men find therein some encouragement toward progress in the science and art of foundry metallurgy and if their seniors are reminded that there yet remains much for them to accomplish through consistent plan and concerted action, its particular purpose and conception will be served.

The following words of closure are adapted from those of a great teacher and leader in the castings industry, the late Richard Moldenke—

To The
FOUNDRYMEN OF AMERICA

*With Whom I Have Worked, From Whom I Have Learned,
To Whom This Lecture Is Dedicated, In Grateful
Memory Of Unvaried Kindness
Constantly Received.*

J. W. Bolton.

April 29, 1943

AN APPRECIATION

In preparation of this Lecture the writer has received helpful advice and criticism from several individuals and groups. To these he extends sincere thanks.

Among these, the following authorities reviewed the sections indicated: Mr. Hyman Bornstein (Gray Iron), Mr. Charles W. Briggs (Steel), Dr. Guillian H. Clamer (Non-ferrous), Mr. Howard J. Rowe (Light Alloys), Dr. Harry A. Schwartz (Malleable Iron).

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Hot-Tear Formation in Steel Castings[†]

By CHARLES W. BRIGGS*, CLEVELAND, OHIO

Abstract

Occurrence of hot tears in steel castings is a cause of much concern in the Steel Casting Industry. The development of non-destructive testing methods has considerably increased the knowledge of this type of casting defect. It is now general practice in most foundries which produce castings for high temperature and high pressure equipment, to use radiographic equipment (X-ray and radium) as a means of pilot casting examination and final inspection for internal defects. Magnetic testing is being used for detection of surface crack and external hot tears. Susceptibility of various cast steels to hot-tear formation, as influenced by various foundry practices, temperatures, contraction stresses, casting design and mold construction, is discussed. The author points to the need for additional information on the subject of hot-tear formation susceptibilities of steels, and suggests correlated testing by foundrymen. In conclusion, a number of hot tear prevention measures are presented.

INTRODUCTION

1. It occasionally happens that in the manufacture of steel castings, defects in the form of cracks are found. These cracks have a very irregular and jagged appearance, and as the fracture face is quite oxidized and shows a heat effect, these cracks are known as hot tears.

2. The Steel Casting Industry in America is very much concerned about the presence of hot tears, and an extensive amount of non-destructive testing is carried on to make certain that steel castings are free from this defect.

3. Considerably more is known regarding the hot tear type of defect because of the general use of non-destructive testing in the steel foundries. Steel casting purchasers, such as the United States Navy Department, have radiographic standards for steel castings, which illustrate examples of hot tears, and advise that their presence in any form is cause for rejection of high pressure valves and fittings, turbine casings, steam chests, low pressure valves and

* Technical and Research Director, Steel Founders' Society of America.

[†] NOTE: Official Exchange paper of the American Foundrymen's Association to The Institute of British Foundrymen.

machinery castings subject to fatigue or impact stresses. Such castings may be repaired, if defective from hot tears, providing that the area is further radiographed and subject to radiographic standards for welding.

CASTING INSPECTION

4. Practically all steel foundries that produce castings for high pressure, high temperature equipment, important ship and ordnance castings, have radiographic equipment available for examination of pilot castings, and for use as a means of final inspection.

5. It would seem of interest to review briefly how steel casting producers are set up to find hidden internal hot tears, and those tears that come to the surface.

6. Five steel foundries have the million-volt X-ray units, 15 additional foundries have industrial X-ray units of varying voltage less than the million-volt units.

7. Eight foundries own radium for industrial radiography. Approximately 150 steel foundries have rented or purchased radium for industrial radiography and, at the present time, there are over 75 steel foundries participating in yearly leases. The United States Navy owns about 17½ grams of radium for inspection of steel castings. The radium capsule usually used contains from 100 to 500 milligrams of radium sulphate.

8. Thus, it will be seen that over 50 per cent of all steel foundries in the United States have had experience with either gamma ray or X-ray radiography for the study of casting technique, and for use as an inspection requirement.

9. Magnetic testing is also being used by steel foundries for the location of surface crack and external hot tears. There are approximately 30 to 40 steel foundries that have magnetic testing equipment available to be used in the inspection of steel castings.

10. Generally speaking, the Steel Casting Industry favors the use of gamma ray radiography because of the portability of radium, its wide latitude in radiographing varying sections, and because radium can be obtained on a rental basis.

11. The above points are brought out, even though it is a deviation from the subject to be discussed, because non-destructive testing is accomplishing so much toward the understanding of the hot-tear problem.

12. From various practical considerations and from certain

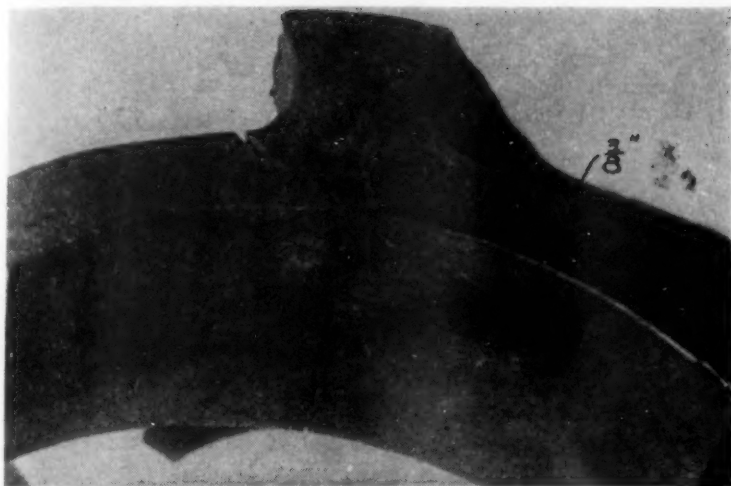


FIG. 1—A—EXTERNAL HOT TEARS IN A SMALL STEEL CASTING.



FIG. 1—B—EXTERNAL HOT TEARS IN A LARGE STEEL CASTING.

experimental observations, it has been established that hot tearing takes place at a temperature not greatly below the solidifying temperature of steel.

TYPES OF HOT TEARS

13. Because of the general occurrence of hot tears they have been divided into two groups¹:

1. External hot tears
2. Internal hot tears

External Hot Tears

14. External hot tears are so-called because the crack defect can be plainly seen on the surface of the casting. The crack first opens on the surface of the casting and proceeds inward. Such a crack has the appearance of a tear; that is, the face of the crack is ragged. The crack is wider at the surface and is uninterrupted in depth and, in some cases, may traverse the entire section, as shown in Figs. 1(a) and 1(b).

15. Cracking or the failure of such a casting could be considered comparable to the failure of a test specimen under load at a high temperature; the cracking begins at surface irregularities, sharp corners, changes in section, and etc., which serve as points of stress concentration. The stresses active in their formation appear to be tensile or shear stresses.

Internal Hot Tears

16. The internal hot tears (Figs. 2 and 3) are found near the center of the section, or that portion of the section where there is a pronounced hot spot, or where solidification takes place last. They are of a decidedly ragged nature, usually with branches. They have no definite line of continuity and nearly always exist in groups. These tears seldom terminate at the surface. When they do appear at the surface they are usually very small and difficult to locate. Upon exploring them downward, they will be found to branch out and become more pronounced.

17. The internal hot tears are regarded as the more dangerous type, since they may be present in a section the surface of which is without defects. Their presence is not realized until they are uncovered by machining or disclosed by radiographic examination.

¹ Superior numbers refer to references at end of this paper.

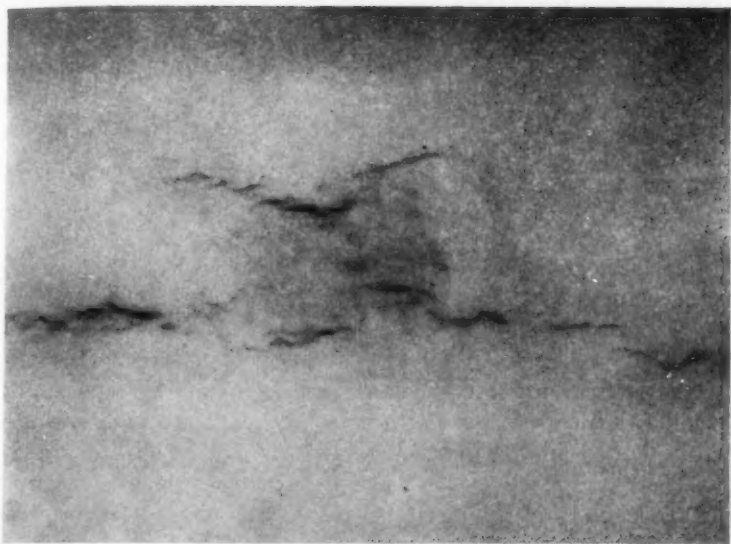


FIG. 2—RADIOGRAPH OF INTERNAL HOT TEAR IN A 2-IN. SECTION OF A STEEL CASTING.



FIG. 3—RADIOGRAPH OF INTERNAL HOT TEAR. TEAR IN SECTION APPROXIMATELY 4-IN. THICK AND EXTENDS ABOUT 3 FT. WITHOUT COMING TO EITHER SURFACE OF THE STEEL CASTING.

18. In some cases they have been treated with indifference, the attitude being that what cannot be seen cannot be considered as harmful. However, it is well substantiated that internal hot tears present in a casting in service may extend until they traverse the section. In so doing they render the casting—for example, a pressure casting—unserviceable.

OCCURRENCES OF EXTERNAL HOT TEARS

19. Hot tears occur because the casting, or a portion of the casting, is under stresses of magnitude sufficient to cause cracking to take place.

20. The presence of the stress is due to the design of the casting, the manner in which the casting cools, and the construction of the mold. Stresses arising from any one of these conditions may be sufficient to produce hot tears.

21. Internal stresses in a casting are proportional to the modulus of elasticity of the cast steel to its coefficient of contraction, and to the difference of temperature involved within the casting. Since the modulus of elasticity decreases with increasing temperature, the magnitude of the stresses necessary to cause permanent deformation and permanent stresses in the casting also decreases. Also, steel has a relatively high coefficient of contraction, and the temperature gradients present in a casting may be quite high. Thus, high stresses are a probability.

22. As steel cools from its solidification temperature to room temperature, it contracts. If it is allowed to contract freely it will have a volumetric contraction of 7.2 per cent for a 0.30 per cent carbon cast steel, which is a linear contraction of 2.4 per cent².

23. However, steel castings do not contract this amount, due to their shape and the fact that the mold material in which they are cast acts to restrain the contraction tendency. The normal patternmaker's shrinkage of 1.87 per cent, which is used in the construction of patterns, is in itself a value of hindered contraction. Some castings may be produced with only a total linear contraction of 1 per cent, or even less.

24. It has been established (Figs. 4 and 5) that as the total linear contraction taking place in the solid state is reduced, the stresses acting on the casting increase². If, for comparative purposes, it is considered that the amount of stress present on a casting at 2000°F. (1093°C.) be 875 lb. per sq. in. for a total contraction of 1.65 per cent, then at 0.95 per cent contraction the

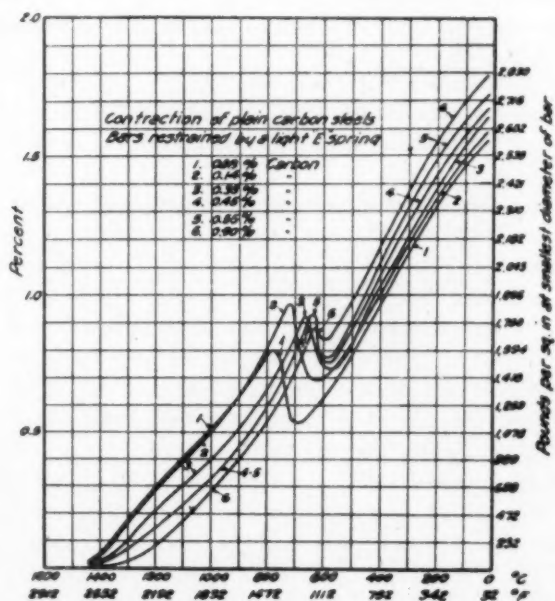


FIG. 4—LIGHT HINDERED CONTRACTION OF PLAIN CARBON STEEL.

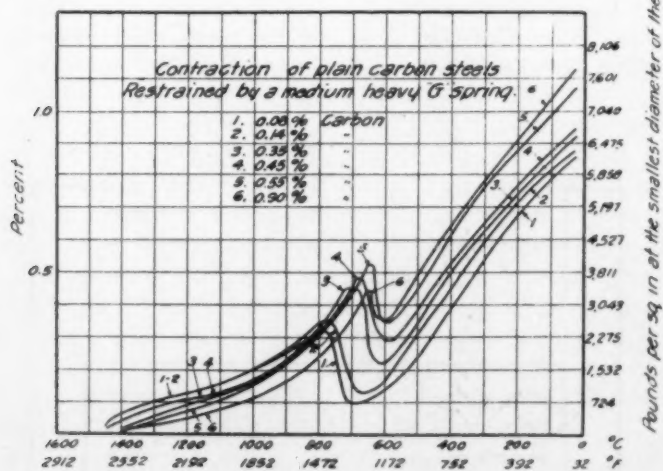


FIG. 5—MEDIUM HINDERED CONTRACTION OF PLAIN CARBON STEEL.

stress would be approximately 1050 lb. per sq. in. In other words, hindered contraction increases the stress acting on the casting.

Hindered Contraction

25. Castings may be hindered in their contraction by (1) the resistance of the mold, and (2) by the shape and form of the casting.

26. The manner in which mold conditions operate to bring about internal stress has been explained in technical writings on the subject of the design of steel castings. There is sufficient evidence to point out that internal stresses arise due to the prevention of normal contraction by the rigidity of sand molds and cores. A simple example will suffice: Figure 6 represents a hard, dry sand mold for a bar with flanges on both ends. It is evident that the sand between the two flanges will prevent the cooling bar from contracting normally. The bar tends to contract toward its center, but the sand, pressing against the inside faces of the flange, prevents it from so doing, and hence stresses are built up in the casting as the casting cools, the bar portion being under a tension stress.

27. In all probability an external hot tear will form at the junction of the bar and flanges. The reason that the casting tears at these points is that the tension stresses that are developed in the bar by the flanges concentrate at the weakest section, which in this case is the junction of the flanges to the bar. The stresses developed were sufficient to exceed the mechanical properties of the metal at that particular temperature, and hot tears were formed.

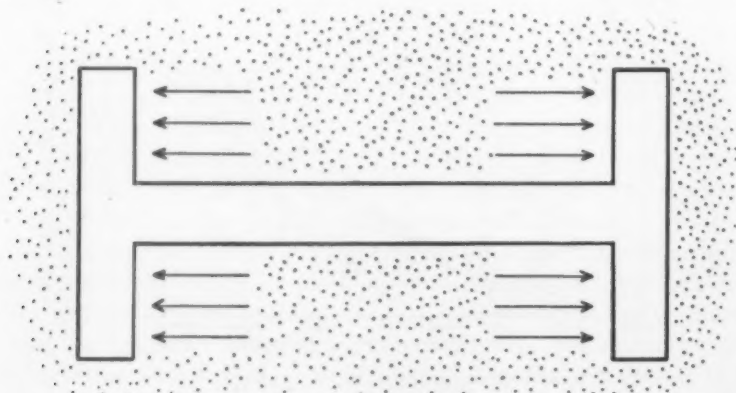


FIG. 6—BAR WITH FLANGES.

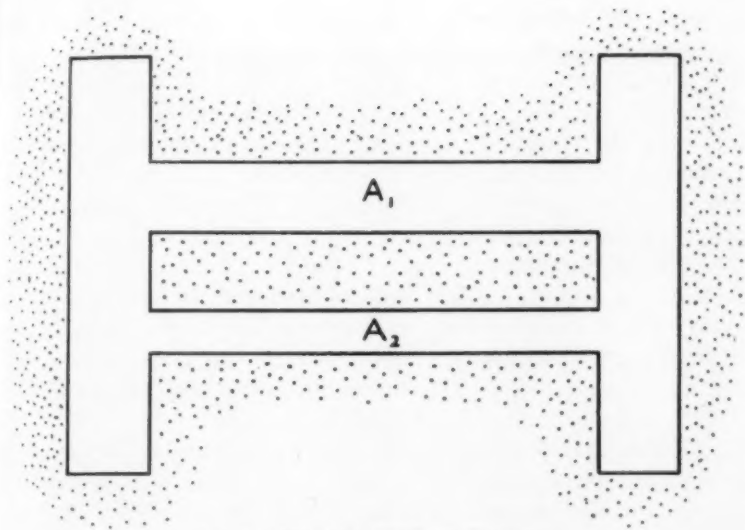


FIG. 7—TWO BARS JOINED BY FLANGES.

28. The location or position of hot tears is nearly always at points of design weakness, such as at re-entrant angles, the joining of sections, or in sections made weak by the presence of hot spots. Hot spots are sections of extra mass usually found at junctions of joining sections. Thus, if hot tearing occurs, it will be at the weakest section which presumably will be the hottest section.

29. It has also been stated that hot tears result due to the shape or design of the casting. This point is illustrated by Fig. 7, showing a design of two bars with flanges, wherein a large bar of cross-section A_1 is joined to a small bar of cross-section A_2 by heavy end sections. Bar A_2 will completely solidify before the large bar A_1 , thus producing a temperature gradient within the casting. This temperature gradient is responsible for a setting up of stresses in the casting, since the amount of solid contraction depends on the temperature and the hindered contraction³. The internal stresses created by these temperature gradients are so great, in this case, that the elastic limit of the material is exceeded. To exceed the elastic limit is not a very difficult condition to fulfill, since steel, at very high temperatures, has low elastic limits and all deformation taking place is principally plastic.

30. The mold-chilling effect and the variation in cross-sectional areas of the two bars cause the wide difference in temperature. Since the contraction of the steel is closely aligned with the tem-

perature, the normal rate of contraction of the two bars will be somewhat different. A possible condition that may exist is shown in Fig. 8. The data plotted here represent that time-contraction characteristic of each bar separated instead of being joined together by the flange construction. The most noticeable variation comes shortly after the steel has solidified. Evidence exists that there may be temperature gradients of as much as 350°F. in a casting of intricate design.

31. Since the two bars are tied together they cannot contract, as shown in Fig. 8, but will take an intermediate course, and the small bar will be in tension and the large bar in compression, with the stresses mounting as the temperature drops. At some temperature the stress acting on the casting is greater than the properties of the steel, and the casting fails from hot tearing.

32. The tears in this case will probably be found at the junction of the small bar and the flange, since the small bar is under tension stresses and the junction is a weak spot and a position of concentration of stresses.

33. Thus, when steel is cast under conditions that tend toward high resistance to contraction, either because of mold resistance or casting design, the magnitude of the stresses acting on the casting is high, the rate at which they build up is fast, and the possibility of hot-tear formation is great.

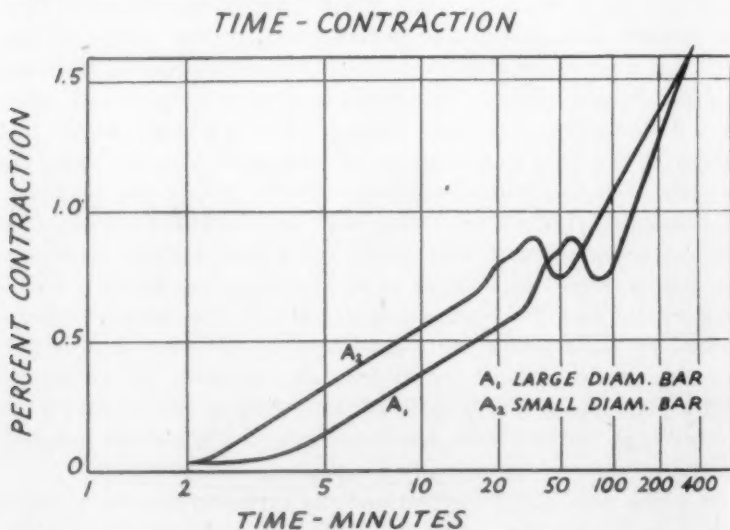


FIG. 8—TIME-CONTRACTION CHARACTERISTICS OF BARS OF DIFFERENT SIZES, NOT JOINED TOGETHER.



FIG. 9—INTERNAL HOT TEARS BROUGHT TO THE SURFACE BY MACHINING A STEEL CASTING.

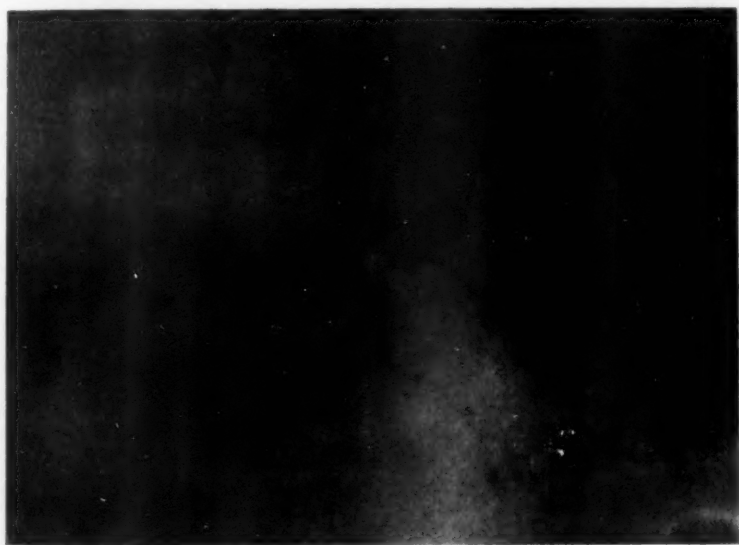


FIG. 10—RADIOGRAPH OF AN INTERNAL HOT TEAR IN A STEEL CASTING.

THE OCCURRENCE OF INTERNAL HOT TEARS

34. Internal hot tears are the result of two effects: (1) conditions similar to those causing external hot tears, that is, prominent temperature gradients which cause solidified sections to pull away from partially solidified sections or completely solidified sections at a higher temperature (Figs. 9 and 10), and (2) solidification contraction which, because of insufficient feed metal, may result in the formation of hot tears in a section instead of the usual shrinkage cavities (Fig. 11).

35. Internal hot tears are caused by stresses built up by temperature gradients. These are the same stresses that cause external tears, only, in this case, the tears start at a location near the center of the section and extend outward. The reason the tears do not come to the surface of the casting is that the skin of the casting is at a lower temperature and is able, because of its higher properties, to withstand hot-tear formation.

36. During the solidification of a section, and for a short period thereafter, there is developed quite an extensive gradient between the skin temperature and the temperature of the center of the section. Thus, the skin, being cooler than the center, is able to withstand greater stress loads.

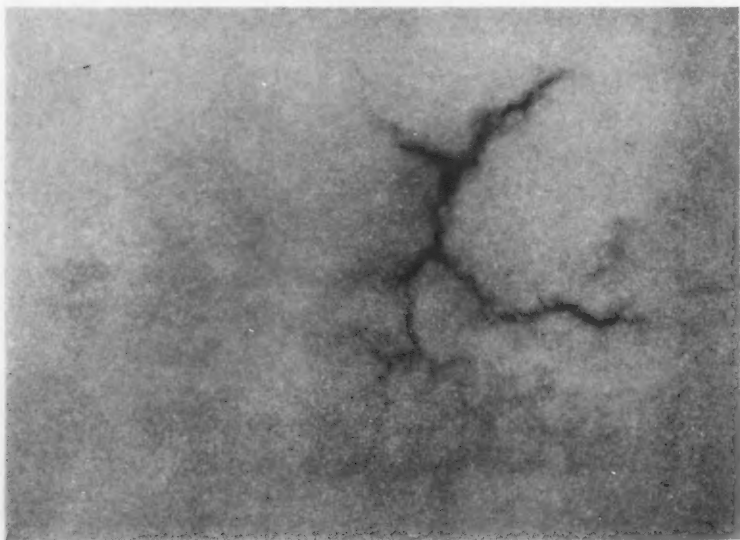


FIG. 11—RADIOGRAPH OF AN INTERNAL HOT TEAR RESULTING FROM SOLIDIFICATION CONTRACTION.

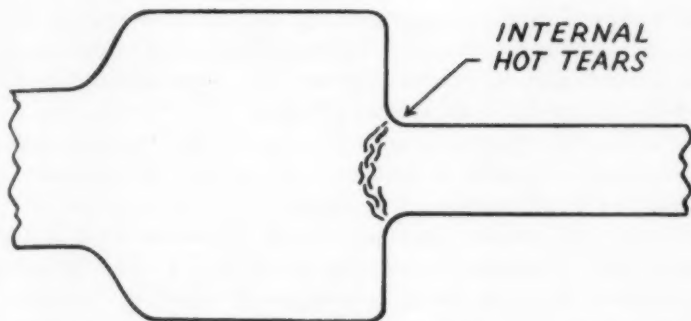


FIG. 12—FORMATION OF INTERNAL HOT TEARS AT A POINT OF STRESS CONCENTRATION.

37. If it is recalled that one section of a casting may be contracting faster than another, and the design of the casting is such that it is an enclosed stress active system, then it is easy to see that tearing may take place in the weak central section of a casting at points of stress centralization without those cracks coming to the surface (Fig. 12).

38. It is also quite possible that this tearing may take place at temperatures greater than those found when external hot tear occurs. In fact, it may take place during the solidification of the casting. At least Singer and Bennek⁵ have found it so, for they

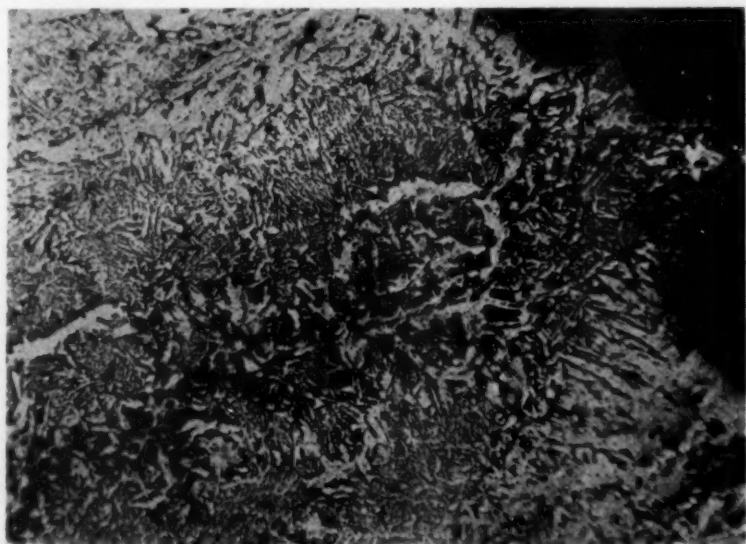


FIG. 13—HOT TEAR SUBSEQUENTLY FILLED WITH MOLTEN STEEL (U. S. NAVAL RESEARCH LABORATORY).

have shown how internal hot tears in the solidified portion of the casting can be subsequently filled with fluid steel in the unsolidified central portion of the section. Such conditions have been found elsewhere, such as is shown in Fig. 13.

39. Also, the tears are of such a shape, and of such random distribution, that it is evident they occurred while the steel possessed very low mechanical properties⁶.

40. It is also quite possible that mold resistance may play a part in the formation of the internal hot tears. This is a point that cannot easily be proved or disproved. However, because of the close proximity of internal hot tears to abruptly changing sections, it is believed that the action of temperature gradients in the formation of stresses is the more important.

41. It has been suggested that solidification contraction may be responsible for hot tear formation. Failure to allow for sufficient molten metal to provide for the steel contraction in volume at the time of its solidification is the reason for the occurrence of these types of hot tears, such as shown in Fig. 11. In uniform sections and in isolated sections, the cavities that normally may form, may form instead as tears radiating out from small cavities, since the contraction of the metal toward the solidifying centers is sufficient to create a stress that tears the last solidifying metal. This stress need not be large, as the metal as it solidifies must, in any case, be very weak.

42. There is a difference of opinion in the United States as to the correct terminology of hot tears formed because of solidification contraction, and there are those who would rather term such defects "internal shrinkage." Since they look like tears, and since it is the desired aim to make this report all-inclusive, they will be treated here as a form of internal hot tears.

43. Which of the two types discussed is the more important in the formation of internal hot tears is difficult to say. All that can be done is to bear in mind that both are effective. The stresses that cause them are apparently tensional ones.

STRENGTH OF STEELS AT HOT TEARING TEMPERATURES

44. It has been stated that hot tears form at high temperatures. What are these temperatures? What are the mechanical properties of cast steel at these temperatures?

45. Prior to 1928 much had been said concerning hot tears and how to prevent them, but little was known of the actual conditions

of hot tearing, such as the cracking temperature or the magnitude of the stresses causing hot tearing. In 1928 Korber and Schitzkowski⁷ produced hot tears in flanged bars by hindered contraction, and decided that the critical temperature at which hot tears are most liable to be formed was about 2300 to 2400°F. They did not, however, measure the stresses on the bars at the time of hot tearing. In 1932 and 1934 Briggs and Gezelius^{2, 8} made a study of the stress acting on a bar during hindered contraction. These bars did not break under the hindered contraction applied, as they were so designed as to prevent points of stress centralization. Since the bars did not break, this work did not show the actual amount of stress necessary to cause hot tears at the hot-tearing temperature, but it did show the load-carrying ability of steel under hindered contraction.

46. In 1936 and 1938 Hall^{9, 10} of Woolwich Arsenal, presented data on the strength and ductility of steel at temperatures near the melting point. In the region of 2300 to 2400°F. he showed that the ultimate stress necessary to cause failure in one-inch bars averaged, for cast carbon steel, from 1700 lb. per sq. in. at 2370°F. to 2500 lb. per sq. in. at 2280°F. There is no indication from this work that the temperature range of 2300 to 2400°F. is more conducive to the formation of hot tears than any other temperature range. In fact, the temperature-ultimate stress curves show nearly

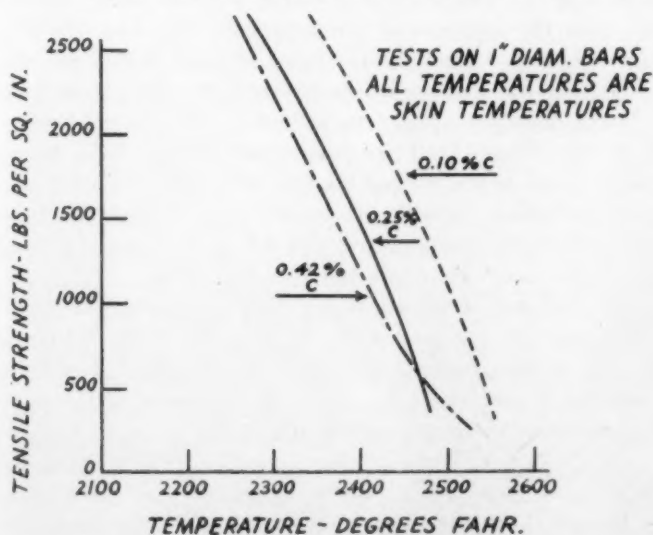


FIG. 14—STRENGTH OF CARBON CAST STEELS AT HIGH TEMPERATURES.

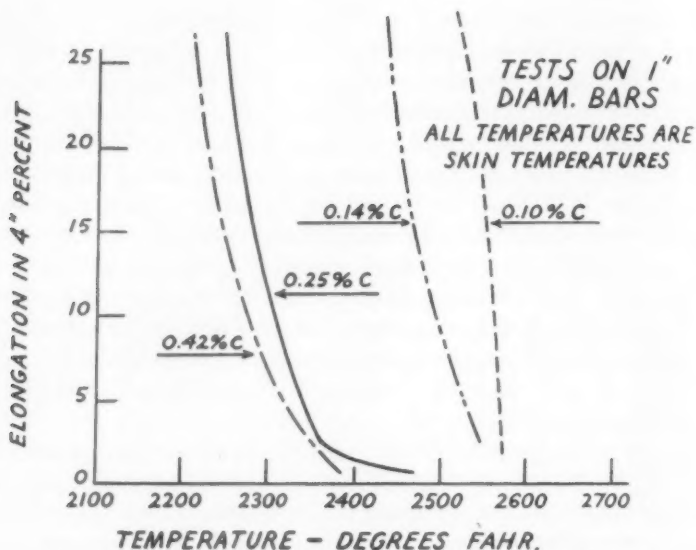


FIG. 15.—DUCTILITY OF CARBON CAST STEELS AT HIGH TEMPERATURES.

a straight line relation in that there is practically a uniform increase in the ultimate strength as the temperature drops.

47. In Fig. 14 there are presented curves showing the strength of different carbon cast steels at elevated temperatures⁹. The curves indicate that the increase of strength with the decrease of temperature is nearly a straight line function, and that the lower the carbon content the greater is the strength at any given temperature. There does not appear to be much difference between the values of the 0.25 and 0.42 per cent carbon curves. This apparently indicates that as the carbon content increases, the strength differential diminishes rapidly. It would appear from these curves that the higher the temperature, the lower the tensile properties, and hence, the easier to obtain hot tear formation.

48. The elongation values of the different carbon steels at the high temperatures are presented in Fig. 15. The curves show that as the carbon content increases the ductility decreases for any particular temperature. Also, the greatest differences in ductility occur at the lower carbon content.

Ductility

49. However, an interesting point is presented by these curves; namely, that for the carbon contents normally produced in com-

mercial practice (0.20 to 0.40 per cent carbon) the ductility is very low until a temperature of approximately 2350°F. is reached in the cooling cycle.

50. Since there is little or no ductility in normal content carbon steels until a temperature of 2350°F. is reached, then only a small amount of deformation is necessary to be responsible for hot tear formation. Also, castings that have failed because of hot tears exhibit sections the fractures of which show no evidence of plastic deformation.

51. Therefore, ductility is a very important property in hot-tear occurrence. It may even be possible to go a step further and state that it appears that the property of ductility is more important than that of strength in the consideration of hot-tear formation.

52. If this be so, then temperatures can be fixed below which hot-tear formation will probably not take place. For steel with carbon contents of 0.25 to 0.40 per cent, temperatures of 2350 to 2300°F. would constitute the lower range of hot-tear formation. Therefore, hot tears may form at any temperature between these temperatures and the solidification temperature of the steel.

53. Because of the increased ductility of low carbon steels (carbon contents below 0.20 per cent) the range of hot-tear formation would be smaller by approximately 200°F., in that ductility values have reached an appreciable figure at 2500° to 2550°F. This would allow an approximate temperature range of only 175° to 225°F. for hot-tear formation for a 0.10 to 0.15 per cent carbon steel, while for the 0.25 or 0.42 per cent carbon steel a range of approximately 325°F. is available for hot-tear formation. This applies to 1-in. diameter sections, and all temperatures recorded are skin temperatures.

54. Variations in temperature between the exterior and interior of a section bring up another point regarding the strength and ductility of cast steel at high temperatures. In steel castings that solidify and cool in the normal way, a temperature gradient exists between the temperature of the skin and the temperature of the center of the bar. Therefore, it is necessary, when reporting property values, that either the skin temperature or the center temperature be used in plotting the results. The temperature is responsible for the recording of different values if different size bars are used in the test studies. Since the skin is at a lower temperature than the center of the bar, and since the lower tempera-

ture steel shows the higher property values, it must follow that the ratio of the area to the circumference of the bar is important in the magnitude of the values obtained.

55. This point is fairly well substantiated in Fig. 16, which shows the properties of 0.25 per cent carbon cast steel, as tested by Hall⁹ on a 1-in. diameter bar, and as obtained by the author on a 1-19/32-in. diameter bar. This ratio on the two bars is as follows:

Diameter, in.	Area, sq. in.	Circumference, in.	Ratio
1	0.79	3.14	0.25
1-19/32	2.00	5.00	0.40

56. From these figures it would appear that as the area increases with respect to the circumference, the effect of the skin on the test values is not so pronounced. The curves of Fig. 16 tend to prove that this condition actually exists.

57. The reason for discussing this point is that when mention is made of the magnitude of stresses at the hot-tearing temperatures, it will not be necessary to develop stress forces equal to or greater than the tensile strength values as set forth in the results presented by Hall.

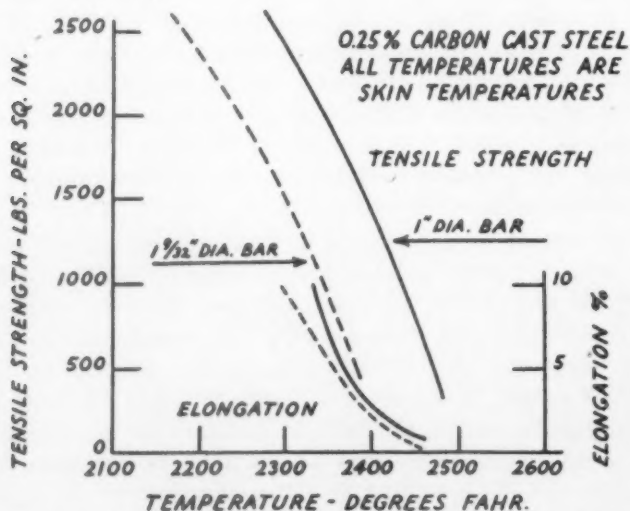


FIG. 16—EFFECT OF SIZE OF TEST BAR ON THE STRENGTH AND DUCTILITY OF CARBON CAST STEELS AT HIGH TEMPERATURES.

Table 1

STRESS QUANTITIES AT HIGH TEMPERATURES

<i>Stress, lb. per sq. in.</i>			<i>Type of</i>	<i>Per Cent Contr.</i>
<i>2500°F.</i>	<i>2400°F.</i>	<i>2300°F.</i>	<i>Hindered Contr.</i>	<i>at Room Temp.</i>
105	210	340	Light	1.7
335	500	625	Medium	1.0
385	560	730	High	0.5

58. In fact, the strength of a 1-in. section in a casting whose width was greater than 1 in. would be less than the values shown by Hall, since the ratio of area to the circumference increases as the width increases. This condition is also true in section thicknesses that are greater than 1 in.

MAGNITUDE OF STRESS DUE TO HINDERED CONTRACTION HOT-TEAR FORMATION-TEMPERATURES

59. It is known² that a 0.35 per cent carbon steel, in the temperature range of hot tearing (2630 to 2300°F.), will develop stress loads under various types of hindered contraction, as shown in Table 1.

60. These figures would tend to indicate that, even under the most drastic conditions of hindered contraction, the stresses developed during the hot-tear formation-temperature interval would not be sufficiently high to cause failure if the values of Hall are used as a basis of comparison. It will be remembered that he showed values in the neighborhood of 2000 lb. per sq. in. as the tensile strength of medium carbon steel at 2300°F. for a 1-in. diameter bar.

61. But it is known that castings do tear at these temperatures and, as has already been pointed out, sections in castings will not exhibit these high strength values.

62. Tensile-strength values at elevated temperatures of medium carbon cast steel that had previously cooled to room temperature have been reported¹¹ to be 250 to 230 lb. per sq. in. at 2250°F. These figures are more in line with the stresses developed by hindered contraction, but it is felt that not too much significance should be placed on these figures since the temperature gradients usually found in steel castings were not present. There is one thing that should be pointed out and that is, the rate of testing used was much slower than that used by Hall, and therefore more in line with the rate at which hindered contraction stresses are built up.

63. Even though the tensile values that Hall shows are not applied to practical application, the actual values of casting section strengths at high temperature are undoubtedly still greater than the amount of stress developed by hindered contraction at the same temperature.

64. The realization of this fact requires that a further consideration be made; namely, that stress concentration is responsible for the apparent discrepancies, so that tearing does occur in accordance with practical observations.

65. It is quite possible that with the differential cooling of a casting, and because of hindered contraction due to mold resistance, stresses will concentrate at a hot spot in the casting, with the result that the casting will tear. The hot spot may have a temperature approaching 2500°F., while other parts of the casting will be at temperatures of 2250° to 2300°F. In such a situation stresses of 250 to 500 lb. per sq. in. could arise through hindered contraction which, if concentrated at the 2500°F. hot spot, would be, even according to the high values reported by Hall, a stress load sufficient to cause hot tearing.

66. Thus, it is possible that small tension or shear stresses, as developed by hindered contraction, are responsible for hot-tear formation, providing that the hindered contraction present is greater than that normally allowed under "patternmaker's shrinkage."

HINDERED CONTRACTION STRESSES PRODUCED BY SANDS AND CORES

67. It is quite easily seen that casting design can be responsible for the stresses shown in Table 1, which is a brief summary of the results found by Briggs and Gezelius^{2, 8}. But what is, perhaps, more difficult to understand is that sufficiently high stresses can be set up through hindered contraction due to sand molds and cores, thereby causing hot-tear formation.

68. However, it can be demonstrated that molds and cores can provide, at elevated temperatures, hindered contraction which is greater than that normally allowed under "patternmaker's shrinkage."

69. Studies¹⁵ conducted on the hot strength of molding sands and cores show that certain mixes develop very high strengths at elevated temperatures, as is shown in Fig. 17. Some sands develop strength of over 1000 lb. per sq. in. in the neighborhood of 2000°F.

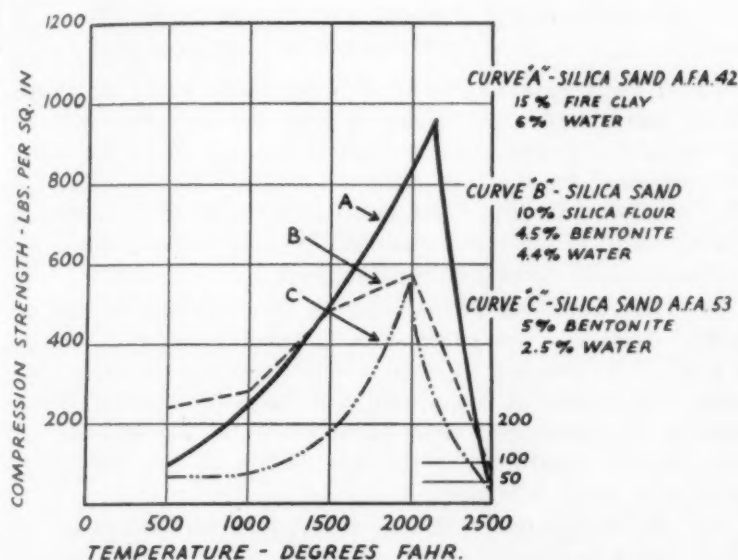


FIG. 17—THE HOT STRENGTH OF VARIOUS SAND MIXTURES.

It is true that they drop off to values of 5 to 100 or so lb. per sq. in. at temperatures near 2500°F. But all these strengths are found in a sand under the actual conditions of casting, since there is a very pronounced temperature gradient that exists following the casting of the steel¹⁶. Thus, while the sand at the mold-metal interface is at a temperature of about 2500°F. and has a strength of perhaps 20 lb. per sq. in., the sand only $\frac{1}{8}$ -in. away from the mold-metal interface would be at about 2000° to 2200°F., and have a possible strength of 1000 lb. per sq. in.

70. Sand of these high strengths will tend to prevent the normal contraction of the casting, with the result that hindered contraction stresses are formed.

71. From the work that has been done it has been established that for steel castings the maximum hot strength, at 2500°F. for sands, probably should not be over 25 lb. per sq. in. If this figure is exceeded by very much the possibilities of hot tearing of the casting increase.

72. Thus, sands and cores, as well as casting design, can be responsible for the formation of high hindered contraction stress at elevated temperatures.

SUSCEPTIBILITY OF VARIOUS CAST STEELS TO HOT-TEAR FORMATION

73. At any gathering of steel foundrymen where the subject of hot tears is discussed, sooner or later the discussion will turn to a debate as to which of the two types of cast steel, high carbon or low carbon, are less susceptible to hot tears. The discussion may also include acid versus basic steel melting practice as concerning susceptibility of hot-tear formation. Opinion among foundrymen is about equally divided on these subjects.

74. The odd thing is that, during these discussions, the subject of stresses or stress formation is seldom considered. Perhaps it is taken for granted, although it is believed that the subject is of such importance that it can hardly be taken for granted, because without the presence of stress there will be no hot tears in well-fed sections, regardless of the composition of the steel or the manner in which it is made.

75. In the first place, the two steels (high carbon and low carbon) cannot be directly compared. Two similar castings produced under similar conditions will not be under the same hindered contraction stresses at a common temperature. For example, it is assumed that one casting is produced from 0.15 per cent carbon steel, and that another similar casting is poured from 0.45 per cent carbon steel. At 2300°F., under hindered contraction conditions, a stress of 750 lb. per sq. in. on the 0.15 per cent carbon steel can be expected; whereas, under the same conditions of hindered contraction, the 0.45 per cent carbon steel will have a stress of approximately only 500 lb. acting upon it².

76. Because of the higher stress acting upon the low carbon steel, the natural reaction would be that the low carbon steel is more susceptible to hot tears. However, this is not the entire story. It must be remembered that the low carbon steel has a much greater strength and ductility at 2300°F. than does the higher carbon steel. If values established by Hall⁹ are used, as they can be considered comparative regardless of the section considered, the low carbon steel is 1.4 times the tensile strength and eight times the ductility value of the high carbon steel at 2300°F. Also, the hot-tear formation-temperature range is considerably smaller than that of the higher carbon steel. Thus, the two types of steels cannot be compared directly as to which is the least susceptible to hot tears.

77. In some cases the high carbon steels will be less susceptible

to hot tears, while in other cases the low carbon steels will resist hot-tear formation more effectively. Which steel to use, to obtain the best results, will depend on the mold conditions and the casting design. It must be remembered that hindered contraction can arise due to conditions of the mold, such as hard molds and cores, or it may reach considerable proportions because of the casting design alone. However, it is suggested that the low carbon steels be first used if excessive hot tearing is encountered, since strength and ductility at high temperatures is necessary to combat stress concentrations at weak sections which are at higher temperatures than other sections.

78. However, if the basic versus the acid practice is considered as to hot-tear formation susceptibility, it is not believed that this can be treated quite so controversially.

Sulphur

79. Inclusions, their content, type and characteristics—as present in a cast steel—have considerable influence on the mechanical properties of the steel at the very high temperatures. It is known that sulphur is quite an active inclusion former and its presence, under certain conditions, can lead to the formation of quite harmful inclusion types.

80. Thus, it would seem that anything that could be done to keep the sulphur content as low as possible would be a step in the

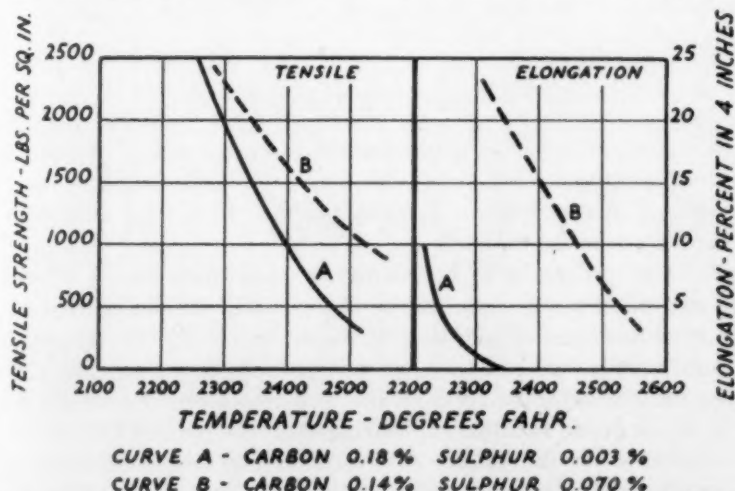


FIG. 18—EFFECT OF SULPHUR ON THE STRENGTH AND DUCTILITY OF CAST STEELS AT HIGH TEMPERATURES (HALL).

right direction regarding the susceptibility of hot-tear formation. It has been shown that as the sulphur content increases, the strength and ductility of cast steel at high temperatures falls off extensively¹⁰ (Fig. 18).

81. By the use of the basic practice it is possible to keep the sulphur content to a low figure. Thus, it would seem that, factors other than sulphur content and inclusion count being equal, basic steels are less susceptible to hot-tear formation than are acid steels.

82. Cast steels having a sulphur content greater than .03 per cent will show, upon deoxidation with a critical amount of aluminum (0.05 per cent), an extensive chain-like eutectic pattern of inclusions¹². Such a condition results in low ductility properties in castings. If the sulphur content is in the neighborhood of 0.02 per cent, there is but little decrease of ductility upon deoxidation with small amounts of aluminum. Low-ductility and-low strength properties are obtained at high temperatures, and are more pronounced than those recorded at atmospheric temperatures. Thus, from the standpoint of hot-tear susceptibility, the sulphur content should be kept low, preferably below 0.025 per cent.

Phosphorus

83. High contents of phosphorus (0.07 per cent) lower the strength and ductility of cast steels at high temperatures, but normal phosphorus contents, below 0.05 per cent, do not have much effect on the high or atmospheric temperature properties of the steel⁹.

INCLUSION TYPES

84. Certain inclusion types present in cast steel are conducive to the formation of hot tears³. Five types of inclusions have been recognized in cast steel in Table 2, together with their sensitivity toward hot-tear formation¹¹.

85. The proneness to hot-tearing of cast steels of the silicate and eutectic types is explained by the fact that atmospheric oxidation produces eutectic inclusions at the surface of the casting, which seriously lowers the resistance of steel castings to hot tearing. The intergranular sulphide form of the ternary eutectic is considered to be more prone to allow hot tearing than the oxide galaxy form. The presence of the galaxy eutectic adjacent to the oxide phase makes the galaxy type of steel less sensitive to hot tearing than the silicate or eutectic types.

Table 2
TYPES OF INCLUSIONS AND SENSITIVITY TOWARD HOT TEAR FORMATION

<i>Type</i>	<i>Non-Metallic Inclusions*</i>	<i>Hot Tear Sensitivity</i>
Silicate	Glassy silicates, round sulphides, and (intergranular sulphide films)	Prone to hot tear
Eutectic	Round sulphides and intergranular sulphide films (alumina)	Prone to hot tear
Galaxy	Alumina, round sulphides and films of oxide galaxies (intergranular sulphides)	Less sensitive
Alumina	Alumina, round sulphides, and (intergranular sulphide films or oxide galaxies)	Resistant to hot tears
Peritectic	Alumina, duplex, round sulphides and (intergranular sulphide films)	Resistant to hot tears

86. The alumina and peritectic types are somewhat more resistant to hot tearing at the oxidized surface owing to the formation of separated oxide particles, rather than to continuous intergranular films. Steels of the peritectic type (deoxidized with calcium) seem to have the same degree of resistance to hot tearing that has been found in the strongly deoxidized steels that are not treated with calcium.

87. These remarks on inclusion types should be looked upon only as trends that may exist, for the other factors that are discussed in this paper require greater consideration. The use of a certain type of deoxidizer is not going to make the steel relatively resistant to hot tearing.

INFLUENCE OF POURING TEMPERATURE ON HOT TEARS

88. The temperature of the steel as it enters the mold is not, directly, a responsible factor for hot-tear formation. Indirectly, however, temperature may be a factor. This may appear to be somewhat confusing. What is meant is that if two steels are poured into similar molds, one a high temperature steel, the other a low temperature steel, the high temperature steel will not be more conducive to hot tears than the low temperature steel. The reason for this is that hot tears do not form until the steel has solidified, and

* Parentheses indicate appearance only in small amounts.

it is necessary for the hot steel to become cool steel before it solidifies. Therefore, there is no difference in the metal characteristics of the two steels as far as favoring hot tearing.

89. However, temperature can bring about altering conditions in mold temperature gradients, and casting design may be such that temperature of the steel contributes to hot-tear formation.

90. It is known that large, uniform section castings should be poured on the cold side, or as cold as the running of the mold will allow. In this practice the mold is not unduly heated at certain places to form hot spots in the casting. Points of change in sections are chilled to prevent hot-spot formations and possible locations for hot tears. Castings of this design and type will probably develop hot tears if poured with high temperature steel.

91. This does not mean that all castings poured with high temperature steel are susceptible to hot-tear formation. In fact, by the use of high temperature it is equally possible to prevent hot-tear formation, and at the same time prevent the formation of shrinkage cavities. If the casting is properly designed to allow for controlled directional solidification¹, then every possible attempt should be made to establish large temperature gradients within the mold and casting. One of the best ways to do this is to use high temperature steel.

92. Thus, the effect that temperature has on hot tearing depends entirely upon the casting design and mold construction.

ALLOY STEELS

93. In this discussion nothing has been said regarding alloy steels and how they react towards hot-tear formation. Like carbon steels, the amount of strength and ductility that an alloy steel possesses at temperatures near the solidification temperature, and the rate at which it contracts under hindered contraction will, in all probability, determine its position as to its ability to resist hot tears.

94. It is suggested that a comparison be made of a nickel-chromium cast steel of 0.35 per cent carbon content with a plain carbon cast steel of the same carbon content. It is universally held that a nickel-chromium steel is quite susceptible to hot-tear formation.

95. From information presented^a it is possible to observe that nickel contents of from 2 to 5 per cent do not increase the tensile

strength or ductility of carbon steel at any particular high temperature. Chromium, in percentages of around 1 per cent, appears definitely to lower the property values, while the combination of nickel-chromium reduces the values below those recorded for chromium.

96. A comparison of values for both carbon and nickel-chromium steels of the same approximate carbon content is shown in Table 3.

97. From these figures it can easily be seen that the nickel-chromium cast steels are much lower in strength and ductility than a corresponding plain carbon steel. Also, the hot-tear formation temperature range is longer.

98. There appears to be but little difference in the rate of hindered contraction of carbon and the nickel-chromium cast steels³, and hence, the rate at which the stress is built up is practically the same. Under a hindered contraction that may normally be expected in casting manufacture, a stress of approximately 500 lb. per sq. in. may be obtained at 2300°F. This is very close to the 840 lb. per sq. in. at zero elongation (Table 3) for the properties of the nickel-chromium steel as compared to the values of 2000 lb. per sq. in. and 7 per cent elongation for the carbon steel. Hence, it is easy to see that the nickel-chromium cast steels are very susceptible to hot-tear formation.

99. It has been stated previously that solidification contraction may be responsible for the formation of hot tears. The information on the amount of solidification contraction in various steels is rather limited and one is called on to make certain assumptions after reviewing all the assembled data on specific volume values. Thus, it appears that the total solidification contraction of a nickel-chromium steel would be, perhaps, slightly greater than that of

Table 3

A COMPARISON OF CARBON AND NICKEL-CHROMIUM CAST STEEL
STRENGTH AT HIGH TEMPERATURES

Temp. °F.	Carbon Cast Steel		Nickel-Chromium Cast Steel	
	Tensile Strength, p.s.i.	Elongation in 4-in., per cent	Tensile Strength, p.s.i.	Elongation in 4-in., per cent
2500	400	0.0	60	0.0
2400	1300	0.5	380	0.0
2300	2000	7.0	840	0.0
2200	3200	33.0	1900	15.0

the carbon steel. If there has been no error in this deduction, then poorly fed nickel-chromium steel would be more susceptible to hot-tear formation (contraction cavities) due to insufficient feed metal, than the plain carbon cast steel.

100. Looking at the problem from these two viewpoints, it is easy to see why the nickel-chromium combination is disliked in the foundry.

101. It might be quite possible to continue at some length on the possibilities of various steels as regards their hot-tear formation susceptibilities, but a considerable amount of the material would be based on general trends instead of actual information. More important information could be obtained if steel foundrymen would carry out additional correlated testing. This would mean that some type of a test must be developed for hot-tear susceptibility.

HOT-TEAR PREVENTION MEASURES

102. The best method of preventing hot tears is to keep hindered contraction stresses to low values. If hindered contraction values are greater than normal "patternmaker's shrinkage" (3/16 in. per ft.), hot-tear formation is a distinct possibility.

103. Measures that should be undertaken to prevent hot-tear formation are as follows:

1. Stresses that result from the hindered contraction of castings due to high-strength molds and cores should be kept at a low value. This is accomplished by using relieving blocks or "firable" material in the backing sand, or by the use of low-strength sand in the cores, as tested at elevated temperatures.

2. See that castings are so designed that they will not be closed; stress active systems wherein temperature gradients may be responsible for large stresses.

3. Make ample allowances for solidification contraction so that every section may be well fed.

4. Produce high quality steel of low inclusion content and of proper inclusion type.

5. Apply proper chills to changes in sections to prevent hot spot formation.

6. Use ribs, or cracking strips, at places to assist in preventing stress concentration.

7. Keep the pouring temperature consistent with the steel casting design.

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The Mass Production of a Manganese Steel Casting†

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Abstract

Due to war demands, it was necessary to greatly increase plant facilities for the mass production of manganese steel castings. The urgency of the situation and the necessity of using facilities and unskilled labor available presented many problems. The author, engaged at the time in designing a plant for the production of mild steel castings, used this plant, in which some equipment had already been installed, as a pilot plant. The melting in this pilot plant was done by the cupola-converter process, which was the first attempt, in the author's knowledge, at mass production of manganese steel castings by this process.

INTRODUCTION

1. Soon after the outbreak of war it was necessary to increase, very considerably, the facilities available for the production of tank track links in manganese steel. The Technical Committee of the Institute of British Foundrymen was asked to design and equip a number of new foundries capable of mass producing these castings, and the author, as Convenor of this Committee, was closely associated with the work.
2. As a consulting engineer, the author was at this time engaged in designing a plant for the production of a casting in mild steel. Some of the equipment had already been installed when it was necessary to change over this plant for the production of the previously mentioned manganese steel casting. It was thus possible to use this plant as a pilot for the new foundries. This paper gives an account of some of the problems encountered and the methods finally adopted in the pilot plant.

MANGANESE STEEL

3. For those who are not familiar with the properties of manganese steel, the following brief description is given. Manganese

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In the absence of the author this paper was presented by John Howe Hall, General Steel Castings Corp., Eddystone, Pa.

steel is the name given to alloys of iron, carbon and manganese, in which the manganese content is within the range 11-14 per cent, with a carbon content of 1.0-1.4 per cent. The ratio between the manganese and carbon contents is important, and in the most satisfactory steels the carbon content is not more, and preferably a little less, than 1/10th of the manganese. For the best results, it is desirable that the composition of the steel be kept within the following limits:

	<i>Per Cent</i>
Carbon	1.0— 1.3
Manganese	11.0—13.0
Silicon	0.5— 0.8
Sulphur	0.06 max.
Phosphorus	0.10 max.

Properties

4. In the as-cast state the steel is relatively brittle, inasmuch as thin sections can be readily broken by blows from a hammer. After heat-treatment, the metal is extremely tough and practically un-machinable. In both the as-cast and heat-treated conditions it is, for all practical purposes, non-magnetic.

5. The contraction which takes place on cooling from the molten state is high, at approximately 5/16-in. to the ft., compared with the 1/4-in. to the ft. allowance usually made for mild steel. The thermal conductivity of the metal is extremely low, the usually accepted value being 0.027 c.g.s. units (0°C.-100°C.), which is only 1/4 to 1/5 that of mild steel.

6. The founding properties of the metal are good and, so far as relative fluidity and "life" are concerned, manganese steel more nearly resembles grey cast iron than carbon steel. In the particular casting under consideration, it was not found necessary to make any special provision for feeding.

THE CASTING

7. The casting which these plants were originally laid down to make is shown in Figs. 1 and 2. It is a simple form of tank track link (since superseded) for a heavy tank. The main dimensional tolerances are ± 0.010 -in. The most important parts of the casting, with respect to dimensions, are the spindle holes, these having to be parallel in both planes within 0.030-in. in a length of 15-in.

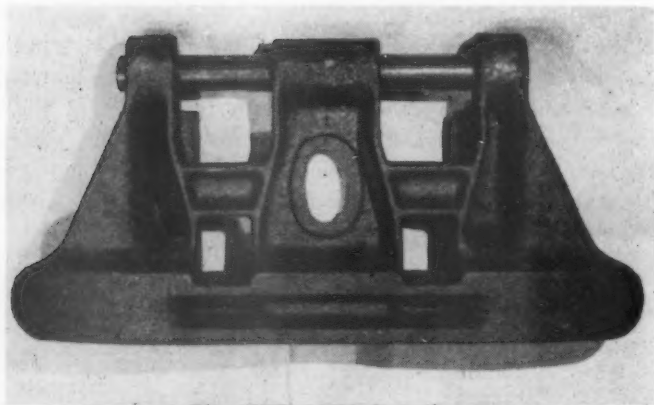


FIG. 1—MANGANESE STEEL TRACK LINK—FRONT VIEW.

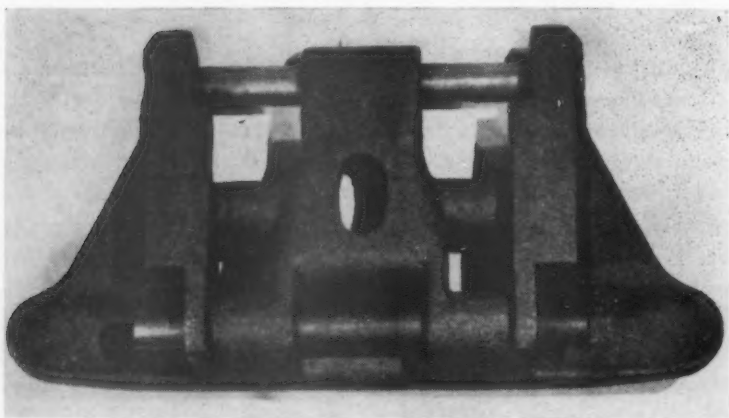


FIG. 2—MANGANESE STEEL TRACK LINK—BACK VIEW.

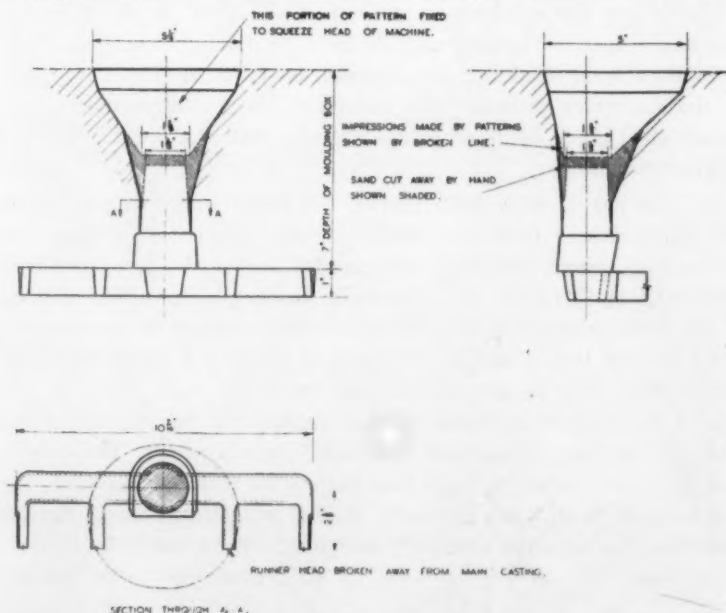
The tolerance allowed on the diameter of these holes is 0.020-in. In Figs. 1 and 2 the spindles can be seen in the brackets which hold them. Three brackets are provided at the one end of the link, and this will, in future, be referred to as the three lug end. These three lugs mate into two lugs at the other side of the next link. The two lug end of the casting, with the spindle running through, can be clearly seen in Fig. 2.

Running and Gating

8. Some difficulties were experienced in deciding on the most satisfactory method of running and gating the casting, and it was actually necessary to proceed with the preliminary lay-outs of the

new foundries before any knowledge was available on the amount of molten metal needed to pour the casting. A temporary wooden pattern was secured and experiments were carried out in the pilot plant, as soon as possible, to obtain this essential information. A small experimental furnace was not available or obtainable at this time, and it was necessary to produce a heat of 2,000-2,400 lb. of steel to pour, say, half a dozen castings for experimental purposes. As will be explained later, in these early days the whole of the labor in the plant was without previous experience of foundry work, and liable to stampede to safety if a few spots of molten metal splashed on the concrete floor. Due to inexperience, and the fact that small heats of steel were wanted only at infrequent intervals, the metal was often cold and of incorrect analysis. Under such conditions it is not easy to decide whether defects are due to metal temperature, composition, mold conditions, or to the method of gating adopted. Therefore, it was something of an achievement when it was finally proved to the satisfaction of all concerned that the casting, which weighed approximately 50 lb., could be successfully poured with 70 lb. of metal.

9. The method of running adopted is shown in Fig. 3, and a casting, exactly as removed from the mold, is illustrated in Fig. 4.



SECTION THROUGH A-A.

FIG. 3—METHOD OF RUNNING AND GATING TRACK LINK.

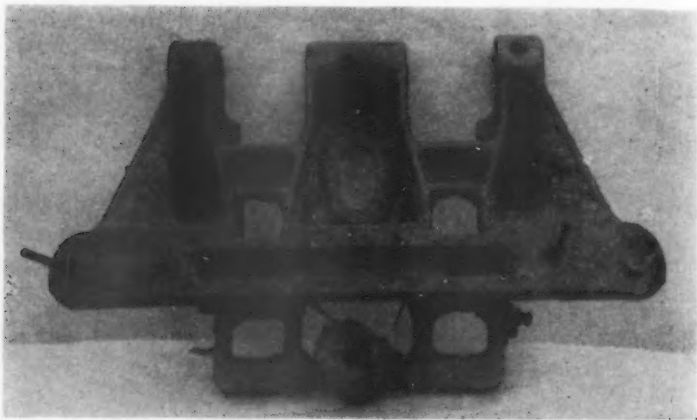


FIG. 4—CASTING AS TAKEN FROM THE MOLD.

LAYOUT OF THE PLANT

10. The output required from the plant to be described was 360 tons* of finished castings per month. The first item to be considered in the layout was the melting plant. Two methods are available for the production of manganese steel in the foundry. The basic electric furnace may be used to produce the steel direct from steel scrap and ferromanganese, or mild steel may be made by the converter process from cupola-melted metal, and the manganese steel made by mixing this with ferromanganese melted in a separate furnace.

11. As has already been stated, the plant under consideration was changed over from the production of a mild steel casting, and the melting plant, consisting of cupolas and converters, had been installed. At this time, no experience was available in this country on the mass production of manganese steel castings by any process, and although the converter process was in use for producing manganese steel, only an occasional heat, or at the most, three or four heats a day were being made by this method. It was estimated that with the melting equipment available, approximately three heats each hour continuously for a nine-hour shift would be needed, that is, a total of 25-30 heats per shift. As far as could be ascertained at that time, no attempt had ever previously been made to produce manganese steel on such a scale by the cupola-converter process.

* Throughout the paper, British weights have been converted to American weights, and this is the reason that some are not round figures.

In spite of this, and of the statement by Briggs¹ that the basic electric furnace is indispensable in the manufacture of manganese steel, it was decided to proceed. In the entirely new plants, basic electric melting and holding furnaces were used, and it should perhaps be mentioned that the melting departments in these plants were not included in the sections designed and equipped by the author.

Labor Consideration

12. Another important point which had to be taken into consideration in connection with the design of the plant, was the need for employing unskilled labor and, owing to the shortage of manpower, the necessity for making the maximum possible use of female labor. Of the labor force of 300 employed, the majority of which was obtained locally, less than 2 per cent had had any previous experience of foundry work. Slightly over 50 per cent were women and girls, of whom many had never previously done manual work. Because of this, it was necessary, wherever possible, to provide mechanical devices to lighten the heavier tasks and enable them to be carried out by women.

13. The layout of the plant is shown in Fig. 5. The total floor area available, of approximately 32,000 sq. ft., is allocated as shown in Table 1.

Molding and Pouring

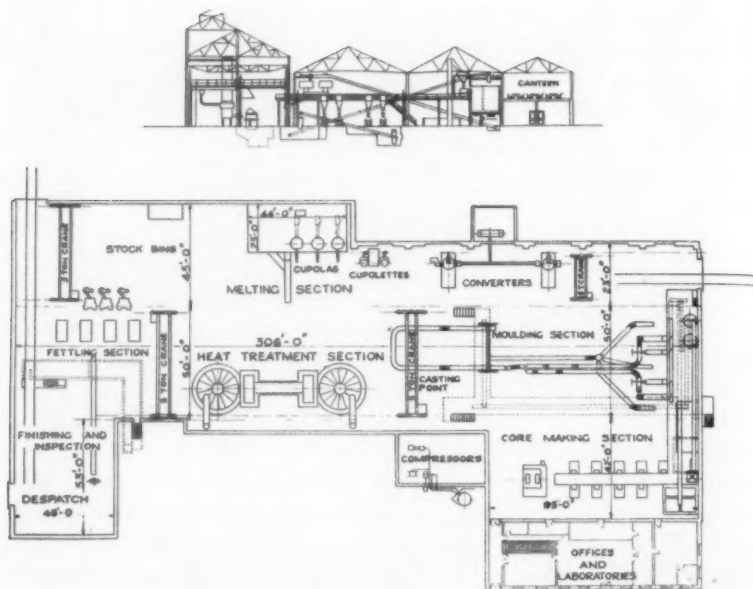
14. Molten metal from a cupola is supplied to a side-blown con-

Table 1

ALLOCATION OF FLOOR AREA FOR VARIOUS SECTIONS

	<i>Dimensions, ft.</i>	<i>Area, sq. ft.</i>
Core-making	95 x 42	4000
Sand preparation, molding and casting	145 x 50	7250
Stock bins and melting	{ 148 x 45 158 x 23	10300
Cleaning	75 x 50	3750
Heat-treatment	85 x 50	4250
Finishing and inspection	30 x 46	1400
Despatch	22 x 46	1000
		<hr/> 31950

¹ Superior numbers refer to references at end of paper.



TYPICAL LAYOUT OF TANK-TRACK-LINK FOUNDRY

FIG. 5—LAYOUT OF FOUNDRY FOR MASS PRODUCING THE TRACK LINK.

verter, and the ferromanganese is melted in a small cupola or cupolette. No holding furnace is employed, so that the metal becomes available in batches approximately 3 times in the hour. For this reason a power-driven mold conveyor is not used. Molding is continuous, the molds produced on the two pairs of molding machines being stored on a horizontal roller track. When a batch of metal is delivered to the pouring station, the molds are pushed along the conveyor by hand, for pouring. Further storage capacity is provided between the pouring station and the shake-out to allow time for cooling, and this also enables the shake-out to operate continuously.

15. From the shake-out the castings are loaded to an overhead cooling conveyor, which transports them to the cleaning section. Here the runners and gates are removed and the castings are roughly inspected, any that are obviously defective being scrapped. A moderate amount of rough grinding can also be carried out. The castings are then heat-treated, finally inspected and assembled.

16. It is only to be expected that some difficulties will arise when starting up a new plant with entirely inexperienced labor,

to mass produce a casting in a metal never previously used in quantity production. While it is not possible in a single paper to discuss all these difficulties in detail, it is hoped to outline some of the more interesting and important of these, and the methods finally adopted. That these methods have been successful may be judged from the fact that the plant, which was designed for an output of 360 tons, has actually produced 550 to 600 tons of finished castings monthly on single shift working.

PRODUCING THE MANGANESE STEEL

The Cupolas

17. Three cupolas are used for supplying metal to the converters. One is used on each shift, while another is being repaired for the next shift. The provision of a third furnace enables major repairs, such as relining, to be carried out without interference with production. The furnaces have a $4\frac{1}{2}$ ft. diameter shell and are lined to 33-in. bore. They are of conventional design, equipped with one row of tuyeres, the only special feature in their construction being a boshed hearth below the tuyeres to increase the holding capacity for molten metal.

Charge

18. The charges used contain 75 per cent to 80 per cent steel scrap, and a melting rate of $4\frac{1}{2}$ tons per hour is obtained. The metal charges are 700 lb., made up as follows:

Carbon steel scrap, lb.	460
Pig iron (0.05 per cent phosphorus max.), lb.	180
Manganese steel scrap, lb.	60
Ferrosilicon (80 per cent silicon), lb.	15-18

The actual amount of ferrosilicon charged depends on the silicon content of the pig iron, which varies from 1.4 per cent to 2.0 per cent silicon. The coke charges are 90 lb., and a limestone charge of 25 lb. is put on with every metal charge. The hearth, when full to the level of the slag hole, holds approximately 2,800 lb. of metal, which is equivalent to four cupola charges. This is the amount of metal normally required as a charge for the converter. Due to wear on the converter lining, the amount of metal required for a charge varies, being lowest when a new lining is used and highest when the lining is nearing the end of its useful life. Therefore, it is not always possible to take exactly four cupola charges for a converter

heat, and the amount required varies between extremes of $3\frac{1}{2}$ and 5 charges. More than one tap is necessary when the converter charge exceeds 2,800 lb.

Tapping

19. Some authorities maintain that, to secure metal of uniform analysis, it is necessary that only complete charges shall be tapped from the cupola. This question has been carefully investigated, and it has been found that within the limits given above, metal of constant composition can be obtained, irrespective of the amount of metal drawn. The fact that a part only of a charge may be melted when a tap is taken does not cause any noticeable fluctuation in the composition of the iron.

Composition of Cupola Metal

20. The composition of the metal produced from the cupola is as follows:

Total Carbon, per cent	2.9—3.1
Silicon, per cent	1.5—1.7
Manganese, per cent	0.7—0.9
Phosphorus, per cent	0.06 max.

Carbon

21. No attempt is made to control the carbon content, as within the limits normally obtained, the influence of this element on the behavior of the metal during its conversion to steel is negligible.

Sulphur

22. The sulphur content, likewise, is unimportant, as a very large proportion of the sulphur is removed when the molten ferromanganese is added to the steel. With a sulphur content of 0.09 per cent, in the cupola metal, the sulphur content of the manganese steel does not exceed 0.03 per cent. At one time it was thought that a high sulphur content in the converter steel might produce inclusions in the finished manganese steel, and the effect of desulphurizing the cupola metal was studied. As far as could be ascertained from microscopic examination, no improvement resulted, and the amount of sulphur remaining in the manganese steel was not affected by this treatment.

Manganese

23. The manganese content of the cupola metal is not allowed,

appreciably, to exceed 1 per cent, as high manganese content results in increased wear on the converter lining and the production of a thin, "sloppy" slag, which is difficult to control. With a view to utilizing more manganese scrap in the cupola charge, higher manganese contents have been tried, but, on the whole, it has been found advisable to restrict this element to a maximum of 1 per cent for the reasons given above.

Phosphorus

24. The whole of the phosphorus present in the cupola metal is retained in the finished steel. This element is also present in the ferromanganese, and in order to meet the specification of 0.10 per cent phosphorus max., it is important that the phosphorus content of the cupola metal should not at any time exceed 0.06 per cent. This question is discussed further at a later stage, when casting defects are considered.

Silicon

25. The most important element in controlling the conversion of the cupola metal to steel is the silicon content. This element is rigidly controlled, because on it depends not only the temperature of the finished steel, but also the time required for the conversion process. In the first few charges at the beginning of a shift, a silicon content of 1.7 per cent is desirable, and this provides a little additional heat which counteracts the effect of a relatively cool converter lining. As soon as the lining reaches a suitably high temperature, the silicon content of the cupola metal is reduced to 1.5 per cent. This gives more rapid converter heats than is provided with a higher silicon content, and enables metal of adequate temperature to be delivered for pouring at suitably short intervals.

The Converters

26. The converters are of the conventional Tropenas side-blown type, and have a nominal capacity of 2,700 lb. A converter body is used for one week, that is, for an average of 170 to 180 heats, and it is then removed for relining. A certain amount of lining repair is carried out between shifts, but this consists chiefly of repairs to the mouth of the vessel. Small hollows, which may develop in the body opposite the tuyeres, are filled with ganister, but these patches are not always successful, and it is found that the most satisfactory results are obtained by relining as soon as the condition of the lining warrants it, rather than by trying to

prolong its life by patching. A lined spare shell is always available for use in an emergency.

27. With this method of operation, the holding capacity of the converter, as already mentioned, increases slightly from the beginning to the end of its life. This is a disadvantage, as for the most successful operation of the plant, a regular supply of a definite quantity of molten metal is desirable. However, the most important point is that the weight of steel in the converter shall be known in advance, within very close limits. Unless this can be accurately forecast, there is danger that the quantities of steel and molten ferromanganese mixed together will be outside the limits capable of yielding a manganese steel of suitable analysis.

28. By careful control of cupola operation, thus ensuring the provision of uniformly hot metal of regular composition, losses during the production of the steel are kept fairly constant and actually average about 12½ per cent. The weight of the molten cupola metal supplied to the converter is carefully checked by means of a dial type weigher on the crane, and it is thus possible to estimate with some certainty the amount of liquid steel which will be available.

Melting the Ferromanganese

29. The ferromanganese is melted in a small cupola, sometimes known as a cupolette. The main details of this furnace are given in Table 2. It will be seen that the shell diameter is 33-in. with an internal bore at the tuyeres of 21-in. The short preheating space

Table 2

DETAILS OF CUPOLETTE FOR MELTING FERROMANGANESE

Shell diameter (external), in.	33
Internal diameter of lining at tuyeres, in.	21
Internal diameter of lining at top of stack, in.,	23
Height from base plate to tuyere centres, ft.	2
Height from tuyere centres to top of stack, ft.	4½
Number of tuyeres	2
Size of tuyeres (inside lining), in.	3x3
Height of coke bed above tuyeres, in.	24
Weight of metal charges, lb. (approx.)	100
Weight of coke charges, lb. (approx.)	12
Blast pressure (taken at tuyeres) in. water	8
Number of charges to fill furnace	7
Holding capacity of well when full to slag hole, lb.	550—600

above the top of the bed coke, coupled with the small tuyere area, enables the required melting rate of 1350 to 1650 lb. per hour to be obtained without difficulty. Hot metal of uniform analysis is obtained, and the loss of manganese during melting is only 6.5 per cent, that is to say, ferromanganese with an average manganese content of 80 per cent when charged, contains 75 per cent manganese after melting.

Lining

30. The lining of the cupolettes consists of one course of $4\frac{1}{2}$ -in. bricks, with a 1-in. facing of ganister in the well and tuyere zone. Spare shells are available, and these are changed after each shift, a spare shell being kept ready for use in case of emergency. The lining in the melting zone, for a height of about $2\frac{1}{2}$ ft. above the tuyeres, wears very thin toward the end of a shift, and the brickwork in this zone is replaced before the furnace is used again.

Slag

31. A free-running slag is produced without the use of lime-stone or any other flux, and is tapped off at approximately half-hourly intervals. This slag contains approximately 50 per cent MnO, and its average analysis is as follows:

<i>Component</i>	<i>Per Cent</i>
SiO ₂	30.0
MnO	52.0
FeO	Trace
Al ₂ O ₃	15.0
CaO	2.5
MgO	0.5

Operation

32. Successful operation of the cupolette depends on the charging of coke and metal of a suitable and uniform size, and in maintaining, as far as possible, a continuous blast throughout the shift. Bridging or hanging of the charges must be avoided, as this leads to fluctuating metal temperature, variable melting losses, and severe lining wear. In order to insure that the charges melt regularly, all coke and the ferromanganese is broken into pieces, approximately 4-in. cube.

33. Molten ferromanganese, at the temperature at which it is tapped from the cupolette, has a very short "life," and it is for this reason that it is necessary to maintain the blast throughout the shift. If it is necessary to shut off the blast for periods of

more than 20 to 30 min., there is a danger that the metal will solidify on the working bottom of the furnace, making it difficult to re-open the tap hole when melting is resumed.

Mixing the Manganese Steel

34. It is not proposed to describe the steel-making process in the converter, and it will suffice to say that the converter is turned down when the flame indicates that the carbon content of the metal is below 0.10 per cent. An addition of ferrosilicon (80 per cent silicon) is then made to deoxidize the bath, and to bring the silicon content up to the desired figure. The amount of ferrosilicon added varies from 20 to 25 lb., according to the amount of metal in the converter. Fairly large lumps are used, and these are dipped in water before being thrown into the vessel. A mild explosion occurs when the moisture comes in contact with the slag covering, and this insures that the addition comes in contact with, and is taken up in, the metal. The bath is then rabbled, and an addition of 3 lb. of aluminum is made, as a safeguard, to insure complete deoxidation. The aluminum is fastened on the end of an iron bar and pushed well under the surface of the metal.

Tapping

35. While these operations are being carried out, the required quantity of ferromanganese, usually about 550 lb., is being tapped from the cupolette. This metal is tapped into a small ladle suspended from the overhead crane, and the weight of the ferromanganese can be roughly checked on the dial-type weigher used on this crane. However, this is not sufficiently accurate for a final weighing, and the ladle containing the molten metal is transferred to a weighbridge as a check. The molten ferromanganese is then poured into the large ladle used for mixing and pouring the steel. The empty ferromanganese ladle is put back on the weighbridge and weighed again. This is a final check on the weight of ferromanganese put into the steel ladle, and is necessary because, occasionally, a skull is left by the ferromanganese. All these operations may sound a little complicated, and some may appear redundant, but experience has shown the necessity for each check if heats of correct analysis are to be produced.

36. The ferromanganese cannot be tapped immediately into the steel ladle because this is too large to be weighed accurately on the weighbridge. Further, if the amount tapped is too great, it is much more difficult to pour a few pounds into a pig mold from a

large ladle than from the small one. Because of the short "life" of the metal, it tends to solidify if poured in a thin stream up the wall of a large ladle, and under these conditions it is not easy to judge the amount poured down.

37. The aim, in this part of the process, is to tap exactly the amount of ferromanganese required by the molten steel in the converter. As already described, the quantity of steel available is known within fairly narrow limits, and molten ferromanganese is needed in the ratio of 1 lb. of ferromanganese to 4.5 lb. of steel.

38. If too much ferromanganese is tapped, there is no special difficulty in pigging a small quantity. On the other hand, if the amount of ferromanganese is found, after weighing, to be insufficient, three courses of action are open. Sometimes the deficiency can be made good with solid cold ferromanganese. However, there is a limit to the amount of solid material which may be used, because of its chilling action on the steel, and the absolute limit of cold metal is 20 to 30 lb. If red-hot ferromanganese, pigged on a previous heat, is available, up to 56 lb. may be added in an emergency. If, due to some mistake in the preliminary weighing on the crane, more than this quantity is required, it is sometimes possible to take the ladle back to the cupolette for more metal. Should there be insufficient time for this, as, for example, when a skull is left in the ferromanganese ladle, then a new calculation must be made, and the amount of converter steel used must be based on the amount of ferromanganese available. This practice is avoided as far as possible, partly because of the difficulty of obtaining a correct reading on the dial weigher suspended above the steel ladle while the steel is being teemed, and because of the difficulty of stopping the pouring from the converter at the correct point. Moreover, the unwanted steel in the converter must be teemed into another ladle and pigged. This is an additional operation, for which time is not really available, and it tends to slow up the production of the next heat of steel.

39. When the ferromanganese has been transferred to the steel ladle, this is taken to the converter and the correct quantity of steel teemed into it on top of the ferromanganese. Slag is prevented from entering the steel ladle by a refractory brick, which acts as a skimmer, held in position across the mouth of the converter. Any steel remaining in the converter, after the required amount has been taken for the manganese steel, is then teemed and pigged. However, in normal practice it is exceptional for this to be neces-

Table 3
MELTING RECORD OF TYPICAL HEAT OF MANGANESE STEEL

<i>Heat 8</i>	<i>Time, a. m.</i>	<i>Weight, lb.</i>
Cupola tapped	10:10	
Weight of cupola metal tapped		2750
Metal in Converter	10:20	
Blast on Converter	10:21	
Ferromanganese tapped	10:28	
Weight of ferromanganese tapped		530
Ferromanganese transferred to mixing ladle	10:32	
Converter blow finished, blast off	10:33	
Additions made to converter:		
Ferrosilicon, 80% Silicon		25
Aluminum		3
Converter metal poured into mixing ladle	10:35	
Weight of manganese steel		2940
Manganese steel ready for pouring	10:40	
Analysis manganese steel:		
Manganese, per cent	13.2	
Carbon, per cent	1.26	
<i>Heat 9</i>		
Cupola tapped	10:30	
Weight of cupola metal tapped		2750
Metal in converter	10:39	
Blast on converter	10:40	

sary. The converter is inverted to remove the slag and is then ready to receive the next heat. Table 3 shows a typical melting record, with times for the various operations.

40. When the molten steel is poured on the molten ferromanganese, an almost completely homogeneous mixture of the two constituents results. Numerous analyses, taken on metal poured at various intervals while a ladle is being emptied, have shown that variations in carbon content do not exceed ± 0.05 per cent, and variations in manganese are less than ± 0.50 per cent. An interesting point is that, no matter how completely the converter steel is deoxidized, there is a loss of manganese, which apparently occurs as the molten steel mixes with the ferromanganese. This loss is practically constant, and is equivalent to approximately 3 per cent of the manganese added. That is to say, the manganese content of the finished steel is approximately 0.5 per cent lower than would be expected by calculation. A heavy manganese loss occurs if the converter slag comes into contact with the ferroman-

ganese, and this question will be examined more closely in the next section.

INITIAL DIFFICULTIES IN THE MELTING SECTION

41. Many of the difficulties experienced in putting the melting section into successful operation were due to cold metal. This was, to some extent, unavoidable, as owing to the inexperience of the molding machine operators, mold production was slow and heats were at first required at intervals of up to one hour. Under these conditions the converter, which at that time was lined down to reduce its output and had a lining 24-in. thick, was never really hot. Even if a start were made with a hot lining, it had ample time to cool down between heats.

42. Because of the low rate of melting required from the cupola, but with the necessity for taking relatively heavy taps, it was not easy to secure hot metal, and the same conditions applied on the cupolette. Experience has since shown the absolute necessity for the hottest possible metal from the cupola, coupled with a continuous series of heats from the converter, if trouble-free operation is to be secured.

43. The lining of the converter is raised to a good, white heat by means of a coke fire, using the ordinary air supply through the tuyeres, before the first heat of the day is put in. After this the heats follow in such rapid sequence, in the normal operation, that the lining is kept hot. If an enforced shut-down occurs in the melting shop, coke is put into the vessel and blown with a gentle air blast until work can be resumed. This practice is also followed during the mid-day break. For the same reason it has been found essential to use ladle heating equipment which gives a really hot lining. For this purpose, high pressure air and gas burners are used, and all steel and ferromanganese ladles are strongly heated before use.

Mixing

44. Some difficulties were also experienced with the method originally used for mixing the manganese steel. At that time it was suggested that, in order to obtain a completely homogeneous steel, it was necessary to pour the ferromanganese into the molten steel in the converter. The ferromanganese ladle had then to be washed out with some liquid steel from the vessel, and this again poured back. The vessel was then rocked once or twice to thoroughly mix

the contents, and the steel was then teemed into the pouring ladle. It was held by authorities using this method of mixing that, if the steel were added to the ferromanganese in the ladle, there might be occasional heats when a good mixture would not be obtained, and castings would vary considerably in analysis, with the possibility that some would be outside the analytical specification.

45. This method of mixing was used for some time, and it was found that unless a large proportion of the converter slag was removed before the addition of the molten ferromanganese, a heavy loss of manganese occurred without a corresponding loss in carbon. As previously stated, in the most satisfactory manganese steel, the carbon content should be not more than, and preferably a little less than, 1/10th of the manganese content. Thus, a steel with a manganese content of 13 per cent would be expected to have a carbon content of 1.25 to 1.30 per cent. If some slag were left on the surface of the converter metal, and sufficient ferromanganese were added to yield 13 per cent manganese in the finished steel, it was found that a carbon of 1.25 to 1.30 per cent resulted, but with a manganese content of 11.0 per cent. Such steel is more difficult to heat-treat successfully than those in which the carbon and manganese contents are in the ratio of 1 to 10. Completely removing the slag was found to be a very tedious and strenuous task, when this had to be done three times in the hour, and it was almost impossible to insure that the operation was carried out satisfactorily on every heat.

46. Other unsatisfactory features were the time taken in this method of mixing, and the fact that the manganese steel had a pronounced erosive action on the converter lining, necessitating heavy patching after every shift.

47. Therefore, it was a most satisfactory solution to a number of difficulties when the present method of mixing was found to yield, consistently, a homogeneous and uniform steel.

Lining Wear

48. Lining wear in the cupolas, cupolettes and converters was the cause of some trouble during the first few months. The cupolas, with a lining of 10½-in. of brickwork, have to melt charges containing 75 to 80 per cent steel scrap for 9-hr. heats. As would be expected, the wear on the linings was heavy, and frequent renewal was necessary. The charges used on the cupola did not contain any silica, the steel scrap was free from sand, and even the pig iron was machine cast. Some reduction in lining wear has been ob-

tained by charging a quantity of siliceous material into the cupola. Ordinary silica sand was at first tried, but it was found that a large proportion of this was lost by being blown out of the stack. The present method is to use a charge of 7 to 10 lb. of sandstone with each metal charge. The actual amount used depends on the nature of the stone, as it was found that some sandstones are more efficient than others.

49. The linings of the cupolettes gave some anxiety at one period, and it was a common occurrence for a part of the shell to become overheated before the end of the shift. The possibility of having to install larger shells with a thicker lining was considered, but it was decided that, if at all possible, this should be avoided, owing to the greater cooling effect a thick lining would have in the early stages of the heat. As already stated, ferromanganese has a short "life" and there is a great tendency for it to chill in the bottom of the furnace.

50. A small amount of limestone was originally used as a flux, and when it was found that this could be dispensed with, some reduction in lining wear resulted. Further considerable improvements were effected by breaking up all metal and coke to a small, uniform size, thus preventing hanging and bridging of the charges. Keeping the furnace full to the top of the stack and maintaining a constant air supply throughout the shift was also found of considerable importance in avoiding lining wear. When the cupolette had to melt for 60 min. in the hour instead of the blast being on for only 40 min., a noticeable improvement in lining life resulted.

Refractories

51. The bricks used in the lining are a high quality firebrick containing 40-42 per cent alumina, and these now give very satisfactory results. It is quite possible that a basic lining is the final answer to the problem of lining erosion in the cupolette. This has been considered, and a lining of magnesite brick was used, but serious difficulties were encountered in producing a suitable slag, and there was a marked tendency for the furnace to bridge over at the tuyeres. Mainly because magnesite and other suitable basic refractories were in shorter supply than firebrick, no further attempts were made to employ them. However, it is of interest to note that when the magnesite brick lining was used, it was found that erosion was negligible after eight hours melting.

52. Mention has already been made of the reduction in lining wear in the converter when the manganese steel was mixed in the

ladle instead of in the vessel. Lining wear cannot now be considered a serious problem, and the capacity of the vessel normally increases from about 2650 lb. at the beginning of the week to about 3500 lb. at the end. As a week's work usually involves over 160 heats, and no internal patching is normally carried out, it is considered that lining life is generally satisfactory. A further reduction in lining erosion has been secured by the use of a sand addition to the converter. About 40 lb. of sharp, silica sand is thrown into the vessel after the slag has been drained at the end of every heat. Some of this sand frits to the lining, and helps in reducing the total wear.

Slag Effects on Linings

53. The effect of leaving slag from a previous heat in the converter was studied, and this was found to have a very serious erosive action on the lining. When discussing the mixing of the manganese steel, it was pointed out that any metal left in the converter had to be poured into pigs. It was thought, at one time, that this operation could be avoided if the steel were left in the vessel as part of the next charge. Unfortunately, the major part of the slag covering has also to be left in, as it is too viscous to be poured off without also losing the steel, the only alternative being to remove it with rakes, which is a very strenuous and exhausting process. Therefore, the slag was left in the converter with the excess steel, and while it had no noticeable effect on the steel-making process, apart from causing a greater amount of projections from the vessel, lining life was reduced by a half, and this method of working had to be abandoned.

LADLES

54. When the first heats of manganese steel were made in the new foundry, bottom ladles, of the type often employed for pouring steel castings, were used. The ladles were lined with firebrick tiles with a facing of ganister. The stoppers and nozzles were of standard firebrick material. It was found that the erosive action of the steel on the stoppers and nozzles was so severe that it was impossible, successfully, to pour the number of castings required. Therefore, a change was made to lip pouring ladles.

55. From the experience gained with the bottom pouring ladle, there appears to be good ground for believing that when a large number of castings has to be produced from one ladle of metal, to

very close dimensional tolerances, lip pouring will produce castings more true to size than bottom pouring. It is believed that when bottom pouring from a full ladle, the pressure of the metal will cause swells sufficient to cause trouble in the assembly of the castings.

Ladle Linings

56. Ganister and firebrick lined lip pouring ladles were used for a time, but very serious trouble was encountered due to a thin, fluid slag, which was continuously produced by the action of the metal on the acid lining. It was almost impossible to prevent this slag from being carried over into the mold with the metal, and rejection of castings due to slag inclusions was high. Erosion of the lining was so severe that a ladle could be used only for two, or at the most three heats, and then had to be relined. Therefore, a change was made to a chamotte lining.

57. The chamotte used contained a high alumina grog, and a lining 3 to 4-in. thick was rammed on top of firebrick tiles. This material was a very considerable improvement on the ganister lining, for length of service and the amount of slag produced during pouring, but it still suffered from the same disadvantages. Slag was still produced the whole of the time the metal was in the ladle, and was of such a thin, fluid nature that it could not be prevented from entering the molds. Various types of skimming devices were tried, without success. Acid refractory skimmers eroded away and produced more slag, which immediately ran into the molds. Basic refractories spalled and washed, and were of little assistance.

58. A noteworthy point in connection with the use of ganister and chamotte ladle linings for manganese steel is that the reaction resulting in the production of the slag also results in a silicon pick-up by the manganese steel. Analyses taken on the first metal poured from a ladle showed a silicon content of about 0.3 per cent, and this was found to increase progressively until the last castings contained 0.9-1.0 per cent silicon. The average pick-up of this element, while pouring a ladle of 2800 lb. of steel, was of the order of 0.5 per cent.

Rammed Linings

59. Finally, a change was made to a new material specially developed for manganese steel ladles then in use at Hadfields Ltd., Sheffield, the originators of manganese steel. This is a basic, monolithic lining material, which is available in two grades, one for

ramming up the ladle, and the other for patching and repairs. The lining material is mixed with water and a little linseed oil, and must be used immediately it has been prepared, as it dehydrates rapidly. To obtain the best results, it should be rammed around a form, and the harder the ramming, the better the life of the lining.

60. The lining must be well vented, and drying in the first stages must be slow and uniform. At the beginning of this operation the lining softens, and for this reason the ladle cannot be inverted. When the lining has become thoroughly hard, the ladle is inverted over a gas burner and the lining strongly heated before use. The average life of a ladle lined in this way is 25 to 30 heats. Although the lining mentioned is fairly robust, it is important that skulls should be avoided as far as possible, as serious damage to the lining may result from attempts to remove a heavy skull. Patching is necessary at intervals, especially around the pouring lip, but this is due to mechanical damage rather than erosion of the lining.

61. With a lining of the monolithic material mentioned, the difficulty of thickening up the slag is completely overcome. Some slag collects on top of the metal when the steel and ferromanganese are mixed, and some of this may, of course, have passed over from the converter. This slag is thickened with a little silica sand, and is raked off. A little lining material is then sprinkled on top of the metal, and this converts any slag remaining into a hard crust. No further slag is produced while the steel is being poured, and one man, using a bent iron bar, effectively prevents any slag from entering the molds. The total loss due to slag inclusions is less than 0.4 per cent, and is not considered excessive when lip pouring an average of 40 molds from each ladle.

62. When the change-over was made to the monolithic lined ladle, no pick-up of silicon was obtained, and it was found that the fluidity of the steel diminished slightly. For this reason, a ferro-silicon addition is made to the converter to bring the silicon content to a figure of about 0.8 per cent.

63. One further point, which may be of interest, is that the heat radiated from the large open ladle was found to be rather trying for the operator who holds back the slag on the ladle. A mask consisting of fine mesh wire gauge was developed. This is fastened round the head and hangs loosely in front of the face, and not only absorbs most of the radiated heat, but has prevented numerous small burns from metal splashes.

THE MOLDING SECTION

Molding Sand

64. Reference to the layout of the molding section in Fig. 5 shows that the sand is delivered, from the main storage hoppers, by a belt conveyor to two mills of the Simpson batch-type. The mills are fed alternately, and the sand is discharged, without further treatment, from both mills into a hopper. From here it is fed to the molding machine hoppers by another belt conveyor, at the same rate as it is produced, and in this way a continuous supply of sand is obtained. Batch mills were installed in preference to a continuous mill, as it was considered that this would allow greater variation of milling time than could be secured with a continuous unit.

65. The sand used is a fairly coarsely graded, sharp silica sand with the approximate mechanical analysis shown in Table 4. This is bonded with a colloidal clay. The green strength obtained with this clay is about 50 per cent that obtained by the use of a similar quantity of bentonite, and the dry strength is less than that yielded by a bentonite addition giving the same green strength. The clay content of the sand is maintained at approximately 8 per cent.

Sand Control

66. Sand control has been found of paramount importance in securing trouble-free operation, and in avoiding casting defects of various types. Routine determinations of green strength, permeability and moisture, are taken continuously throughout the shift, and the properties are kept within the following range:

Green Strength, lb. per sq. in.	9—11
Permeability	130—150
Moisture, per cent	3.9—4.3

67. A shatter test is also employed, and has been found a most useful index of the molding properties of the sand. For this test, an A.F.A. standard test core is dropped from a height of 6 ft. to a steel plate. The shattered core is placed on a $\frac{1}{2}$ -in. mesh wire screen, and that remaining on the screen is weighed.* The weight, in grams, is reported as a "plasticity" figure.

* Recommended by Mr. John J. Sheehan.

Table 4

SIEVE ANALYSIS

	<i>British Standard Sieve No.</i>	<i>Equivalent Tyler Sieve No.</i>	<i>Per Cent</i>
Remaining on	16	16	0.5
	30	32	25.0
	44	42	55.0
	60	60	16.0
	100	100	3.0
	150	150	0.5

68. It has been found, that under the conditions of operation in this plant, and with a green strength in the range given above, a plasticity of 120 to 135 should be maintained. If the plasticity figure falls below 120, trouble is experienced from molds becoming broken after closing, either before or during casting. With a plasticity figure of more than 135, there is a tendency toward hot tears in the castings.

69. One further test, which has been found of considerable value, is the mold hardness test. Too great a ramming density has been found to increase the possibility of hot tears developing in the castings. Therefore, tests are taken at frequent intervals to insure that the hardness of the mold face does not exceed 80 to 85. On the other hand, readings must average more than 70 to 75, if swollen castings are to be avoided.

70. The bond addition is made as the molding sand is fed from the main storage hoppers to the mills. The bonding agent is stored in a bin situated above the belt conveyor, and is fed to this by a rotary table. The layer of sand on the belt is opened and closed over the bonding agent by ploughs, as it has been found that this prevents bond being lost as it falls, with the sand, into the mill. The weight of bond added is controlled by the time the table is allowed to rotate, as each individual batch of sand passes to the mill. The quantity added is varied to suit requirements, but is usually of the order of 5 lb. in a batch of 600 lb. of sand.

71. When a manganese steel casting is removed from the mold, a thin skin of fused sand grains is found adhering to it. An analysis of this slaggy material shows it to contain a considerable proportion of manganese, and it is probable that the fused material is a silicate of manganese. While the casting is hot, this fused sand is attached to it quite firmly, but, fortunately, when the full contraction of the metal is reached, it falls away. The fused sand is

not suitable for returning to the system, and it is removed by screens from the sand carried to the cleaning shop, and dumped.

72. Each casting poured thus represents a certain loss of sand, and it was decided that the weight of the new sand added to the system should be based on the number of castings produced. In practice, it has been found that a new sand addition of 5 lb. per casting adequately covers all sand lost from the system. The new sand is fed continuously from a separate bin at a rate of 5 lb. for each mold produced. This sand enters the system on the conveyor which carries the molding sand from the shake-out to the main storage hoppers, and is not added to each batch of sand at the mills.

Molding

73. The machines used are of the pneumatic, jolt-squeeze, pin-lift type, and are operated entirely by girls. Production averages 55 to 60 molds per hr., from each pair of machines. Over 1000 molds are obtained, per shift, from the two pairs of machines installed. Wooden lifters are used in the deep pockets on either side of the link in the top part of the mold. These pockets can be clearly seen in Fig. 1. It has been found that when sand conditions are ideal, the lifters are unnecessary, but it is not possible to maintain these conditions continuously in practice, and the lifters are always used.

Mold Handling

74. The weight of a half mold is 260 lb., and it was impossible for girls to lift this weight, unaided, from the machines to the roller track, and at the same time secure the necessary production. A simple but effective mold lift-off and turn-over device was developed to reduce the physical effort involved. It consists of an overhead trolley fitted with hangers which locate in the trunnions of the molding box. When the molding machine lifting mechanism is retracted, the box is left suspended from the trolley and can be turned over and transferred to the conveyor with a minimum of effort. This device, which is used on each machine, is illustrated in Fig. 6.

75. The bottom and top parts of the mold are deposited on separate runs of roller track. The bottom part is transferred to a carriage fitted with rollers, which travel at right angles to the direction of travel of the carriage. While on the carriage the mold is

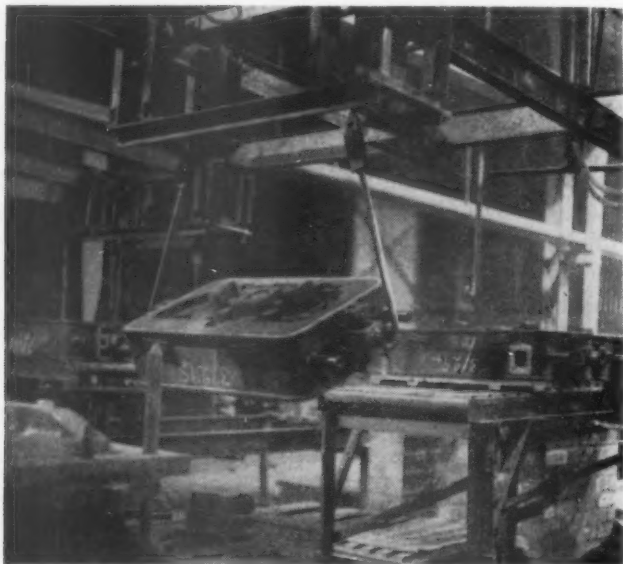


FIG. 6—MOLD LIFT-OFF AND TURN-OVER DEVICE.

cored up and brought to the point where it is joined by the top part. The top part of the mold is raised by a small pneumatic hoist and lowered on the bottom part. Pneumatic hoists were installed primarily because of the long delivery of electric hoists, but they have proved very satisfactory in operation, and enable closing to be carried out slowly and smoothly by girls.

76. The completed molds are clamped and pushed down the roller track toward the pouring point, also by girls. Storage space is available for 60 molds, and an average batch of metal will pour between 40 and 45 castings.

CORE-MAKING

77. In the core-making section, only unskilled labor was available; in fact, the making of the cores, inspection and setting in the molds, and the supervision of all this work had to be carried out by operatives without any previous foundry experience. Careful consideration was given to the arrangement of the cores, and it was decided that a number of simple cores would be preferable to a few of a more complicated type. The set of 12 cores used is shown in Fig. 7, and these cores are made by hand, at a rate of approximately 1250 sets per shift, by 30 unskilled girl coremakers. A fur-

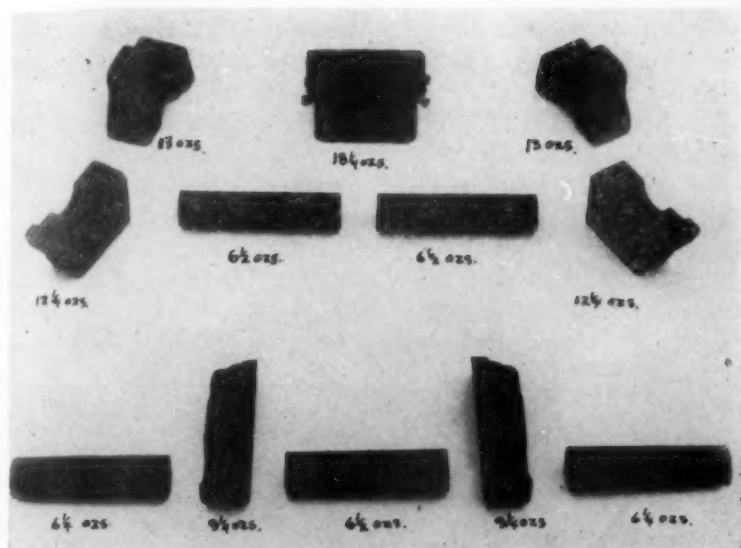


FIG. 7—CORES USED FOR TRACK LINK CASTING.

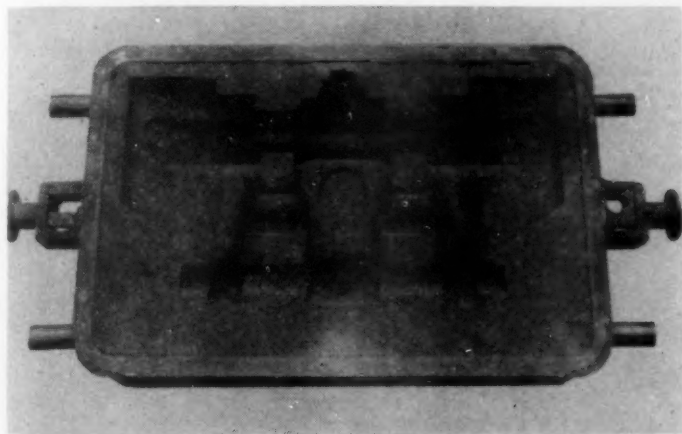


FIG. 8—TOP PART OF TRACK LINK MOLD.

ther advantage of the simple cores is that they can be dried on flat plates without distortion.

78. The top part of the mold is shown in Fig. 8, and the bottom part in Fig. 9. The method of setting the cores is shown in Fig. 10. It should be particularly noted that a separate core is used for each spindle bracket. It is essential that the three spindle cores on the one side, and the two on the other side shall be completely

in line. A tolerance of only 0.020-in. is allowed on these holes, and they must be parallel in both planes within ± 0.030 -in. in a length of 15 ft.

79. At first sight, it may appear advantageous to use a single long core on either side, and this method was adopted in certain of the plants. The alternative arrangement of coring is shown in Figs. 11 and 12. However, experience has shown that with unskilled labor, the simpler cores are easier to make and assemble without faults, and allow much more rapid production to be obtained. Each of the spindle cores is provided with a greensand register in the mold, and thus the correct location of these cores

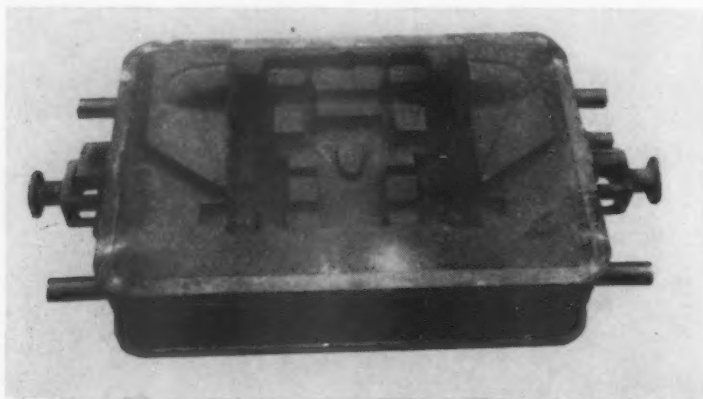


FIG. 9—BOTTOM PART OF TRACK LINK MOLD.



FIG. 10—BOTTOM PART OF TRACK LINK MOLD, SHOWING CORES IN POSITION.

does not depend on the satisfactory setting of other cores. The greensand registers can be clearly seen in Fig. 9.

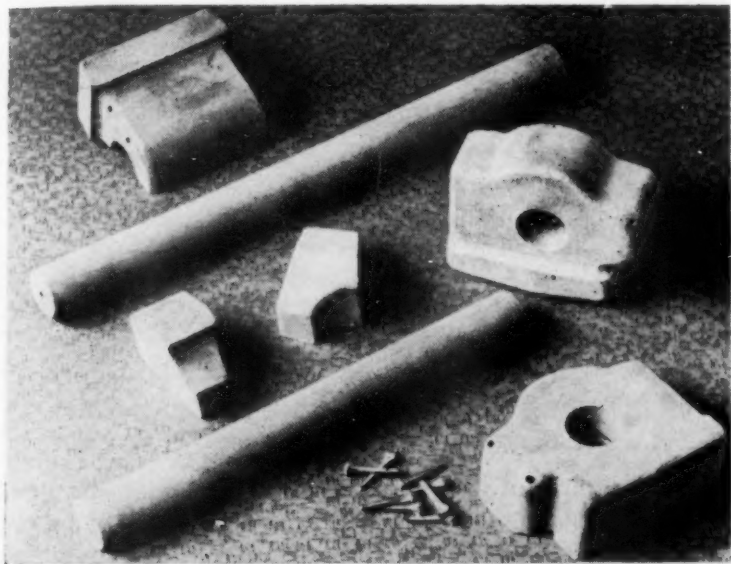


FIG. 11—ALTERNATIVE ARRANGEMENT OF CORES FOR TRACK LINK.

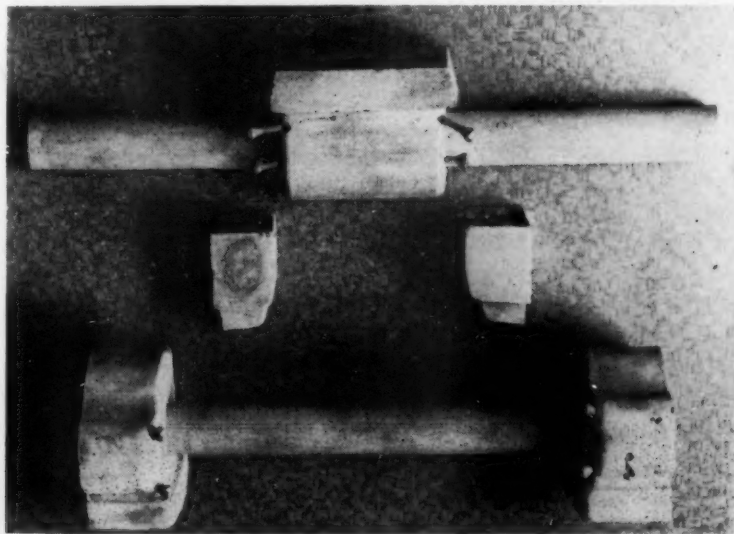


FIG. 12—ASSEMBLY OF ALTERNATIVE CORE ARRANGEMENT.

Core Sand

80. The sand used for the cores is a fine-grained silica sand, containing about 2 per cent of natural clay. The grading of this sand is shown in Table 5.

Table 5
CORE SAND GRADING

	<i>British Standard Sieve No.</i>	<i>Equivalent Tyler Sieve No.</i>	<i>Per Cent</i>
Remaining on	22	24	0.6
	30	32	0.4
	44	42	1.2
	60	60	44.0
	100	100	38.0
	120	115	9.0
	150	150	5.5
	200	200	0.7
	300	270 (approx.)	0.6

It is mixed with 3 per cent of a proprietary core binder, and yields a core sand with a green bond of approximately 3 lb. per sq. in. and a permeability of 80. An advantage of using this finely graded sand is that no wash is required, and no trouble is experienced with metal penetration.

Handling and Distribution

81. The handling and distribution of the core sand is carried out by conventional means. The sand is first passed through a drier, and is then raised by a bucket elevator to a bin above the mixer, the latter being situated on a platform. A specially developed measuring device attached to the bin insures that the correct quantity of sand is loaded into the mixer. The mixed sand is discharged into barrows, and distributed in this way to the hoppers above the core-making tables. Bulk handling of the sand prevents air drying, and precautions are also taken to prevent drying of the sand on the tables. The bottoms of the hoppers are provided with sliding gates, which must be raised when a supply of sand is taken for use.

Core Drying

82. A vertical continuous stove is used for drying the cores, and from this they are loaded into storage racks. From here the

cores pass through inspection and are made up into sets for transporting to the molding section.

SHAKE-OUT

83. After pouring, the molds are pushed round the roller track toward the shake-out. Storage capacity is provided to allow time for the castings to solidify and cool to a temperature where removal from the mold cannot cause damage. Because of its very low thermal conductivity, manganese steel cools slowly, and at least 15 min. is allowed between pouring and shaking out.

84. The shake-out used is illustrated in Fig. 13. It consists of a vibratory device attached to a pneumatic hoist, the whole being mounted on an overhead runway. The boxes are provided with bars and must be shaken out in halves. With this device, one man can deal with over 1000 molds, that is, 2000 box parts, per shift. The top part of the box is lifted by its trunnions and swung toward the shake-out grid. As it passes near the grid the vibrator is operated and the sand falls away. The box part is then deposited on an inclined roller track which returns it to the molding stations. The vibratory device is then swung back and deals with the bottom part in the same way, except that the box is turned over as it is



FIG. 13—PNEUMATIC VIBRATORY SHAKE-OUT.

vibrated, to release the casting. The total time taken in the two operations is less than 20 seconds.

85. The sand is not shaken out directly over the grid, but to one side of it. This is done for two reasons, the first being that unless the hot casting falls on a deep cushion of sand, there is danger that the spindle brackets may be knocked seriously out of alignment. The second reason is that the author considers it fundamentally wrong to supply sand to a belt conveyor sporadically in large quantities.

86. The conditions under which the shake-out belt operates are always severe, but wear and stretching are considerably increased if the sand is not fed at a fairly uniform rate. Therefore, the used sand is fed through the grid by shovels, and this method has the added advantage that any large pieces of metal spillage, fins, etc., which could cause serious damage to the belt, are picked out.

87. An important point to be considered in a foundry making manganese steel castings is that metal fins, shot, etc., entering the sand are non-magnetic, and cannot be removed by magnetic means. Care is taken to see that all metal spillage on the top of the mold is scraped off before the box passes to the shake-out. Any of the larger pieces of metal are picked out when the sand is being thrown through the shake-out grid, and two screens are installed in the system for further cleansing. The latter also tend to break down most of the unburnt cores. This core sand is allowed to enter the molding sand, and no attempt is made to reclaim it for use in the core mixture.

STARTING THE MOLDING SECTION

88. Perhaps the main difficulty experienced in this section was in securing the required production from the molding machines. When work began, estimates of the ultimate mold production put forward by the foremen and operators varied between 10 and 20 molds per hr. Production, with new and completely inexperienced operators, as would be expected, was at first slow, and this led to difficulties in the melting shop. During this period it was not easy to maintain uniform sand conditions, as frequently very few molds would be cast, and unpoured boxes were shaken out. Unused sand, passing back through the system often received additions of bond and moisture which were not required, with the result that the

plasticity rose until it was impossible to produce a good mold. This was only remedied by making large additions of new sand.

89. It was found that when the strength of the sand, as indicated by the green compression test, rose above 12 lb. per sq. in., the sand was discharged from the mills in hard lumps, and so was not in a suitable condition to produce good molds. This trouble was corrected by placing a definite upper limit on the green strength allowable.

90. The fact that metal shot and fins could not be removed from the sand by magnetic means was not discovered until the plant was in operation, and suitable screens were not immediately available. The metal content of the sand rose to somewhat alarming proportions, and it was at one time impossible to take up a handful of sand which did not contain a number of pieces of steel. Remarkably, this appeared to have no effect on the castings, apart from an occasional small surface blemish, which could be removed in fettling, but it did begin to cause damage to the patterns, which were of aluminum. The installation of more and suitable screens completely overcame this particular problem.

91. Little trouble has been experienced due to the necessity for using hot sand, which occurs when the plant has been in operation for 3 to 4 hr. The sand finally reaches a temperature of about 100°F. No provision had been made for heating the patterns, and for a time, bad lifts were experienced when hot sand began to circulate. It was finally found that the use of a spray consisting of 50 per cent paraffin (kerosene) and 50 per cent linseed oil, was of great assistance in preventing sand sticking to the pattern.

92. When the plant was first put into operation, the molds were placed on wooden bottom boards on the roller track. These boards very quickly became damaged, and it was decided that the molds must be poured without the use of boards. This led to a considerable rise in scrap due to broken molds. However, modifications were made to the sand, to the degree of ramming, and also to the method of handling the molds on the tracks, with complete success, and it was unnecessary to replace the bottom boards.

CLEANING

93. From the shake-out the castings are transported, by an overhead conveyor, to the cleaning section. Because of the low thermal conductivity of the metal, which causes cooling to be

abnormally slow, it is necessary to arrange for accelerated cooling of the castings by means of water sprays, and this also assists in cleaning. On reaching this section, the castings are sufficiently cold to be handled, and the runner is broken off by a blow from a hammer. The portion of the gates which remain attached to the casting are also broken away. Any fins and sand remaining in the pockets are removed with pneumatic chipping hammers. After heat-treatment, the metal is very difficult to chip, so that all chipping must be carried out at this stage.

94. In the as-cast state the castings are relatively brittle, and although they will withstand fairly rough handling, there is a danger that this will start small cracks which will be opened up on heat-treatment. Suitable precautions are taken to prevent the castings being excessively hammered, thrown about, or dropped on one another, or on the floor. A rumblor of the wheelabrator type was installed for cleaning before inspection, but its use had to be abandoned when it was found that over 50 per cent of the castings so treated showed hair cracks after heat-treatment.

Grinding

95. Local overheating of the surface by heavy grinding also causes hair-cracking, and such grinding is not permitted on unheat-treated castings. Where necessary, grinding is carried out as gently as possible after heat-treatment.

96. After cleaning, the castings are inspected and gauges are used to check up on overall dimensions. The total scrap at this stage averages approximately 2.5 per cent.

HEAT-TREATMENT

97. In order to obtain the maximum ductility and strength from manganese steel, it is necessary to soak the castings at a temperature of 1000-1100°C. (1830-2010°F.), and quench in water from this temperature. The carbon content of the steel may be between 1.0 and 1.4 per cent, and in the as-cast condition, some of this carbon exists as free carbides in the form of small lakes, arranged as a network. This is the reason for the relative brittleness of the unheat-treated steel.

98. The object of the heat-treatment is to take these free carbides into solution and retain them in solution by quenching. If the heat-treatment cycle is correct, a wholly austenitic structure should be produced. Figure 14 shows the structure of the as-cast

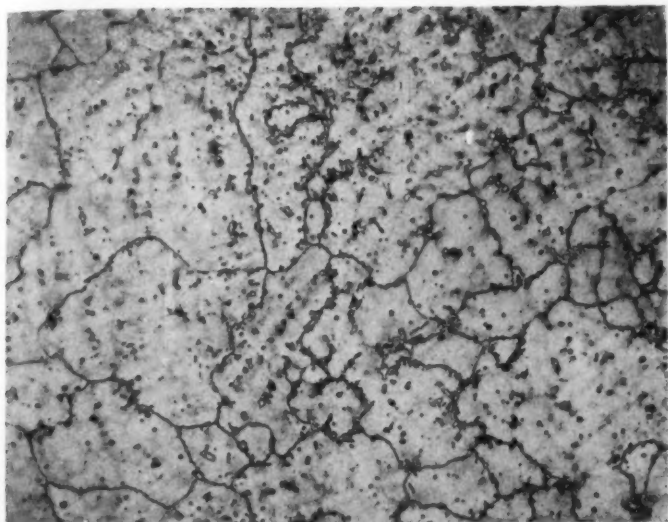


FIG. 14—MANGANESE STEEL AS-CAST. ETCHED 2 PER CENT NITAL. $\times 100$.

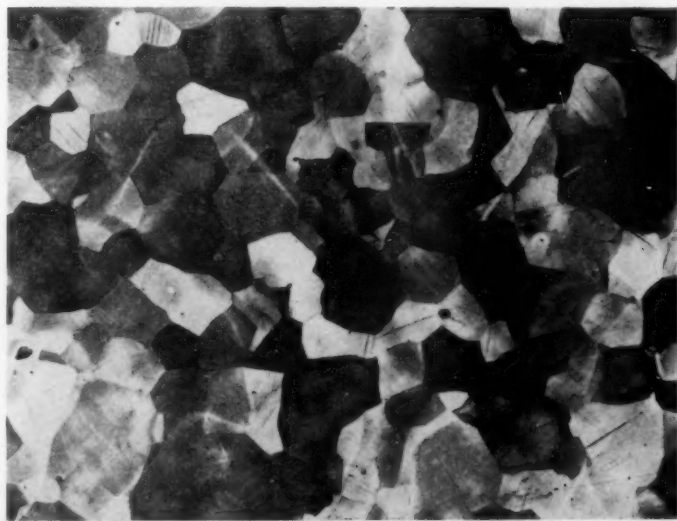


FIG. 15—MANGANESE STEEL, WATER QUENCHED FROM 1050°C. (1920°F.). ETCHED 2 PER CENT NITAL. $\times 100$.

metal, and Fig. 15 the structure obtained after correct heat-treatment.

Heat-Treatment Furnace

99. In view of the large quantity of castings to be heat-treated,

very careful consideration had to be given to the type of furnace to be employed. Up to that time all furnaces used on this service were of the batch type, or enabled a very slow initial heating to be obtained. Hall² describes a furnace used for the heat-treatment of miscellaneous castings in manganese steel, in which the castings are allowed 45 min. to attain a temperature of 500°C. (950°F.), and approximately a further 30 min. to reach 1000°C. (1830°F.). Clark and Coutts³ recommend 100°C. per hr. as a suitable rate of heating up to 750°C. (1380°F.), and soaking at this temperature, to insure uniformity, before accelerating the heating up to the desired temperature.

Temperature Rate

100. When dealing with relatively brittle castings, having a very low thermal conductivity, it would appear, at first sight, unwise to heat them rapidly to a high temperature. However, the author was convinced that, to handle the necessary production in the space available, it would be necessary to use a continuous heat-treatment furnace, and to charge the castings into a fairly high temperature. It can now be admitted that it was with some trepidation that the decision was finally taken to install a gas-fired rotary hearth furnace, as shown in Fig. 16.

101. This furnace is provided with a hearth divided into 15 stations, which can be rotated round a central axis. The castings to be heat-treated are charged in at one door and make a complete circuit of the furnace before being discharged at another door, one station removed from the charging point. With a temperature of 1050°C. (1925°F.) at the discharge, it is possible, with the best adjustment of the burners, to reduce the temperature by 100°C. at the charging door, giving a temperature of 950°C. (1740°F.), and it is into this temperature that the castings are charged.

Furnace Operation

102. The operation of the furnace is extremely simple. Six castings are charged to a station, as shown in Fig. 17. These castings are allowed to remain in this position for 11 min. before the hearth is moved around by one station, to enable a further six castings to be charged. The complete cycle to the quenching point thus takes 2½ hr., and is made up of approximately 45 min. in heating up to 1050°C. (1925°F.), and 105 min. at this temperature.

103. Operation is continuous, and each time six links are dis-

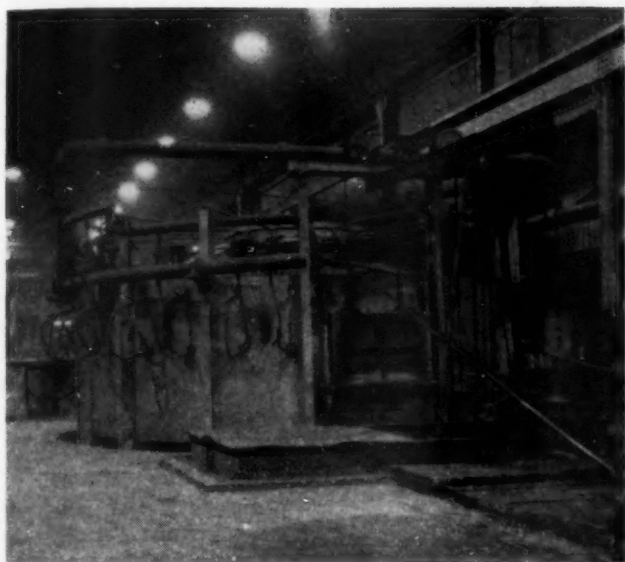


FIG. 16—GAS-FIRED ROTARY HEARTH FURNACE, USED FOR THE HEAT-TREATMENT OF MANGANESE STEEL TRACK LINKS.

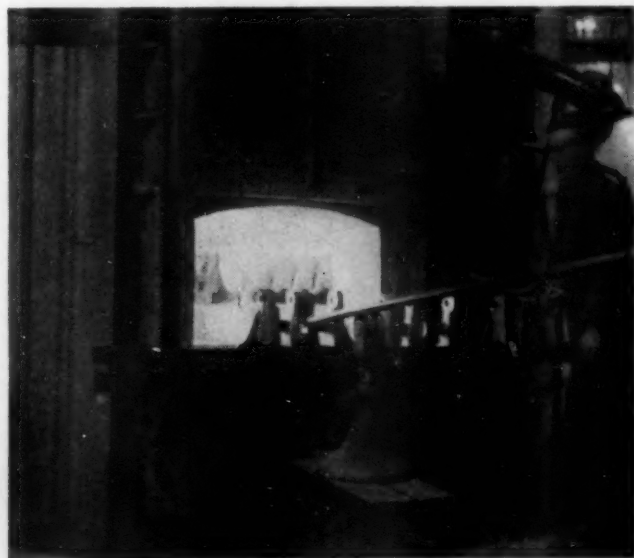


FIG. 17—CHARGING POINT OF ROTARY FURNACE, SHOWING METHOD OF LOADING TRACK LINKS.

charged and quenched, a further six castings are charged. The simple apparatus installed for loading and discharging is very effective, and enables both these operations to be effected in less than 30 seconds.

Quenching

104. The method adopted for removing the links for quenching is shown in Fig. 18. The castings, on entering the quenching tank, fall into a steel basket, which is replaced, by means of the overhead crane, at regular intervals. Scale, which falls to the bottom of the tank, is removed periodically. The heat-treatment section is operated 168 hr. per week, and there is no difficulty in handling the whole output of the foundry in the two furnaces provided.

Scaling

105. A very important consideration, in the establishment of a correct heat-treatment cycle, is the question of scaling. Because these castings had to be made to such close dimensional tolerances, it was impossible to decide on the final dimensions of the patterns and core boxes until reliable information was available on the



FIG. 18—DISCHARGE POINT OF ROTARY FURNACE, SHOWING TRACK LINKS BEING UNLOADED FOR QUENCHING.

amount of metal which would be removed by scaling. Preliminary tests were made in a small, experimental batch furnace, and this enabled final adjustments to be made rapidly when the continuous furnaces were put into operation.

106. When production started in the new furnaces, the problem was to secure the correct microstructure in the castings without excessive scaling, which would have necessitated major alterations to the patterns and core boxes. This was successfully accomplished, and the final scaling results in a loss of approximately $\frac{1}{64}$ -in. from the surface of the castings, that is, an increase of $\frac{1}{32}$ -in. on internal, and a decrease of a similar amount on external dimensions. In order to keep the pitch of the links correct, it is essential that there shall be no wide variations from the average scaling, and every care has to be taken to keep constant both the temperature and atmosphere of the furnaces. Recording pyrometers enable control to be obtained over the temperature, and control over the atmosphere is obtained by manual adjustment of the burners, as considered desirable after the examination of quenched castings for depths of scale. These tests are taken, at frequent intervals, on castings removed from the quenching tank.

107. An interesting point in connection with scaling is the dimensions of the cores used for the spindle holes. It will be seen from Figs. 17 and 18 that the castings are charged into the furnace so that they stand on the two-lug end. The spindle holes in the three-lug end are nearer the burners, and it has been found that the scaling in these holes is more than that which takes place in the spindle holes in the two-lug end nearer the hearth of the furnace. Because of the small tolerance allowable on the finished diameter of these holes, it has been necessary to provide cores for the three-lug end spindle holes 0.025-in. diameter smaller than those used in the two-lug end. It is also worthy of mention that the diameter of the core boxes used for the spindle cores in the three-lug end is exactly the same as the diameter of the finished holes. That is to say, in this particular case, the expansion of the core on drying, the contraction of the metal on cooling from the molten state, and the scaling on heat-treatment all cancel each other out, and result in a hole exactly the same size as that in the core box.

108. It may appear wasteful, especially under the present emergency conditions, to allow the castings to become cold before they are again heated for quenching. The author is firmly of the

opinion that, under normal conditions, it is always advisable to carry out cleaning operations before heat-treatment. In the interests of fuel economy this question was investigated, and a trial was made in which castings were taken at a temperature of approximately 900°C. (1650°F.) from the shake-out and charged into the heat-treatment furnace. It was proved that a satisfactory microstructure could be obtained with a very short heat-treatment cycle, of the order of only 30 min.

109. However, a serious difficulty was encountered in the removal of the runner from the hot casting, and it was found that at a high temperature this would bend, with the danger of seriously distorting the casting, but would not break. All cleaning had to be carried out after heat-treatment, and chipping away fins, etc., thus became impossible. This very considerably increased the time required for cleaning. Charging the castings into the furnace and quenching them at the rate at which they were produced presented many problems, and the attempt was finally abandoned.

FINAL INSPECTION AND ASSEMBLY

110. When the castings are removed from the cleaning tank they are delivered by the overhead crane to the finishing and inspection section. Here the castings are carefully inspected for size and defects. Representative castings are jigged to check all main dimensions. The actual finishing required is very small, and consists mainly of removing scale and any slight surface imperfections from the spindle holes. Scale can be easily removed by hammering, and high-speed grinders are also used, but the number of castings requiring grinding is small.

111. The heat-treated castings are sufficiently ductile to enable spindle brackets, which have become slightly out of alignment in heat-treatment or at the shake-out, to be knocked into line with a hammer. No welding is permissible, and castings are rejected if any slight draw or other shrinkage defect, slag hole, etc., is present in a vital part, such as the spindle brackets or roller paths. Any heavy grinding which may be necessary, for example, the removal of a part of a gate left on during cleaning, is also carried out at this stage, but here again the percentage of castings requiring such treatment is not high.

112. The scaling, which occurs on heat-treatment, sometimes reveals defects which were not apparent on the rough inspection in the cleaning section. Cracked castings are more readily iden-

tified, owing to the action of the heat-treatment in opening up fine hair cracks, and the same applies to small draws and slag holes. The total rejects on final inspection do not average more than 1 per cent, making the total of rejected castings from all sources a little under 4 per cent of the total production.

113. It might be mentioned here that one important reason for keeping the scrap to an absolute minimum, which does not arise where the steel is made in the electric furnace, is that there is a limit to the amount of scrap which may be remelted. Under present production conditions, approximately 25 per cent of the scrap castings and sprue is remelted in the cupola charges, and the remainder has to be sold. Fortunately, there is a ready market for this scrap among iron foundries, some of which find such material useful for increasing the manganese content of cupola mixtures.

Assembly

114. When finished, the castings are assembled, with their spindles, into batches of six links, and each batch is checked for correct pitch by being passed over a standard sprocket wheel, as shown in Fig. 19. This is known as the wrap test, and is the most



FIG. 19—TESTING PITCH OF ASSEMBLED TRACK LINKS ON STANDARD SPROCKET WHEEL.

important of the dimensional tests. The sprocket of the first link is fitted tightly against a tooth on the test wheel, and this link thus becomes the driving link. The wheel is then turned until all the link sprockets are engaged. Each casting must seat well down on the wheel, and then the clearance between the sprocket of the last link and the corresponding tooth is measured. For the sub-assembly to be passed, this clearance must be not less than 0.25-in., and not more than 0.35-in. The retainers for the spindles are then fitted and the sub-assembly is ready for despatch.

METALLURGICAL CONTROL

115. When producing heats of manganese steel continuously, by the process used in this plant, there is a possibility that, due to a combination of adverse conditions, a heat of steel may be made with a composition outside the specified limits. This does happen on very rare occasions, though the plant has sometimes run for weeks without a heat of wrong analysis.

116. However, it is necessary, when the need arises, to find every casting poured in any particular heat. In order that this shall be possible, each casting is numbered. A pattern number is fixed permanently to each pattern, a date number is also fixed to the pattern, but changed each day, and finally, every mold made from each pattern is numbered consecutively, the number being imprinted on the mold face. At the same time, the pattern and casting number is chalked on the side of the box, as can be seen on referring to Fig. 6. As each heat is poured, a girl records the numbers of the castings, and thus, at the end of the shift, a complete record is available, giving not only the number of each casting in every heat, but also the relative position of each casting during pouring. Should a heat prove of wrong analysis, the castings can be found and rejected during the rough inspection in the cleaning section.

117. During the early stages when the plant was being put into operation, this casting record was found of the greatest value in assessing the cause of the various types of defects encountered. A copy of the record was sent to the cleaning section, and the condition of each casting examined was briefly entered against its number. The record then went to the final inspection, where further details were recorded. In this way it was possible to examine the influence of both pouring temperature and composition on the various defects encountered.

118. One point revealed by this system, for example, was that certain castings, which had the appearance of having been poured with cold metal and which contained cold laps, were actually poured first in the heat with the hottest metal, and the defects were due to discontinuities in pouring from a full ladle.

Cracks in Manganese Steel Castings

119. One of the most serious metallurgical problems encountered was in preventing the occurrence of cracks in the castings. It must be remembered that when these cracks were first met, many of the conditions in this plant—for example, at the shake-out, in the cleaning section and in heat-treatment—differed widely from anything previously attempted in the manufacture of castings in manganese steel. A disconcerting feature of the trouble, which suggested that none of these conditions could be entirely responsible, was that all the castings did not crack, one being found badly cracked, and perhaps the next casting in the same heat, which had apparently received identical treatment, would be quite sound.

120. Cracks, in various forms, persisted for some time before being brought under control, and a very complete series of investigations was carried out to determine their causes, including examination of the influence of pouring temperature, temperature of the casting at the shake-out, rate of cooling, treatment in the cleaning section, the rate of heating and the position of the casting in the heat-treatment furnace, as well as the effect of composition and mold conditions, etc.

121. The cracks were found to be of two main types, large cracks present in the castings prior to heat-treatment, which will be referred to as hot tears, and smaller cracks, usually only discernible after heat-treatment, which will be called hair cracks.

Hot Tears

122. This type of crack could usually be detected on rough inspection before heat-treatment, and generally occurred on one or more sides of the square recesses in the link between the spindle brackets and the road face. These square recesses can be seen on referring to Fig. 1. The blue coloration of the fractured surface showed that these cracks were formed during the cooling of the castings from the molten state, and that the castings were at a fairly high temperature when the crack developed. When very small, these cracks might not be identified in the cleaning section,

and were then found at the final inspection after the heat-treatment had opened and spread them.

123. Experience showed that four main factors were responsible for this type of defect, and they are arranged in what is considered to be their correct order of importance, as follows:

1. *High Carbon.* Too high a carbon content in the steel, especially if the carbon is high in relation to the manganese content, will increase the tendency to the production of hot tears. A casting containing a carbon content of 1.4 per cent is more likely to tear than one containing 1.2 per cent carbon, and a casting containing 1.2 per cent carbon with 13 per cent manganese is less likely to crack than one containing 1.2 per cent carbon with 11 per cent manganese.

The effect produced by the converter slag, when allowed to come into contact with the molten ferromanganese, and its influence in yielding a high carbon content with a relatively low manganese, was discussed earlier in the paper. Another factor, which will produce similar results, is the stopping of the converter blow before the whole of the carbon has been eliminated from the steel. The aim should be to produce converter steel containing not more than 0.10 per cent carbon.

2. *High Phosphorus.* Published information^{3, 4} suggests that phosphorus, up to 0.125 per cent, has no deleterious influence on manganese steel castings. However, positive evidence has been obtained that this element greatly increases the tendency for the production of hot tears in mass-produced castings in this metal. In one test, all other conditions were kept constant and five heats were made with a phosphorus content of 0.08 per cent to 0.09 per cent. A further five heats were then cast with the phosphorus increased to 0.12 per cent to 0.13 per cent. More than 200 castings were poured in each range. Of the high phosphorus castings, no less than 61 per cent were rejected because of hot tears, while the rejects in the low phosphorus range totalled only 3.5 per cent.

In the acid lined converter, such as is used in this plant, there is no possibility of removing phosphorus when the steel is made, as may be done in the basic electric process. All phosphorus present in the cupola metal and in the ferromanganese goes into the steel. The ferromanganese normally contains 0.20 per cent phosphorus, which means that when the manganese addition is made to the converter metal, the phosphorus content is increased

by about 0.04 per cent. If all other conditions are satisfactory, little trouble may be expected from hot tears if the phosphorus content of the finished steel does not exceed 0.10 per cent. Therefore, the phosphorus in the cupola metal must be kept below 0.06 per cent, and preferably below 0.05 per cent. This can only be done by using the best quality steel scrap and pig iron in the cupola charges.

3. *Incorrect Mold Conditions.* Too strong a mold, that is, the use of molds rammed too hard or made with sand of very high dry strength, has been shown to increase the tendency to produce hot tears. It was found that excessive moisture, especially if used in conjunction with high bond, would produce these defects. This high moisture and bond are revealed by the use of the plasticity or shatter test already described, and it is necessary that the properties of the sand shall be kept within the specified limits and that excessive mold hardness be avoided.

4. *High Pouring Temperature.* Investigation showed that the first castings poured from any heat were more prone to show hot tears than castings poured later, when the metal was cooler. A high pouring temperature, say in excess of 1500°C. (2730°F.), produces long, columnar crystals in the castings, and these are apparently a source of weakness during cooling. Cracking was frequently found to occur in this type of crystal formation.

124. One slightly incorrect condition may not be sufficient to cause serious trouble from hot tears, but experience has shown that a combination of more than one of the above factors, which individually would not be considered serious, can cause a considerable loss of production from this source.

Hair Cracks

125. Two types of hair crack were experienced, (1) cracks produced during quenching, and (2) cracks produced by rough handling of the castings in the as-cast condition.

1. *Quenching Cracks.* These cracks are only produced when the free carbide in the castings has not been wholly taken into solution before quenching. As would be expected, this trouble was met in castings in which the carbon content was high, especially if the ratio of manganese to carbon was less than 10:1. It has been proved that, with a sufficiently long soak at a suitable temperature, quenching cracks can be avoided, even if the carbon

is higher than normal, but under production conditions it is not possible to vary the heat-treatment to suit the composition of the metal, and this is another reason why it is important that the metal composition should be kept within the specified limits.

2. *Cracks Produced by Rough Handling.* In most cases it was established that cracks, found after quenching, were made more easily detected by the heat-treatment cycle. If the structure of a casting containing hair cracks is examined, and no free carbide is found, this is taken as proof that the cracks were produced before quenching. Rough handling of the castings in the as-cast state, such as throwing them down, excessive hammering, rumbling, etc., will produce minute cracks, which are opened out and increased in size by heat-treatment.

Cracks are likely to be produced when short pieces of fins, whistlers or gates are knocked off, and by heavy grinding, before heat-treatment, to remove such pieces. Very rapid heating of the casting from the cold is also avoided, as this not only produces cracks by thermal shock, but also increases the tendency for any minute cracks, already present, to spread. It has been found necessary, in this connection, to allow at least 15 min. for the castings to reach a temperature of 500°C. (930°F.) from the cold.

Testing the Metal

126. Routine tests carried out on the metal include chemical analysis, which is made on every heat, hardness tests and metallographical examination.

Test Sample

127. For analysis, a special test sample is cast when approximately half the metal from a ladle has been poured. This is taken, while still red hot, and placed in a muffle at a temperature of 900°C. (1650°F.) for 30 min., and afterwards removed and allowed to cool in air. The sample can then be drilled, using a heavy drilling machine, and a 1/2-in. diameter, high-speed steel twist drill, running at about 150 r.p.m. Samples not heat-treated in this way cannot be drilled successfully. Before the heavy drilling machine was used, an attempt was made to secure a pellet sample for analysis by pouring the liquid steel from a height of about 15 ft. into water. This method of sampling was found to be unreliable, the silicon content of the metal, especially, differing from that obtained on drillings.

Micro-Examination

128. Micro-examination is usually carried out on samples taken from actual links after heat-treatment. The sample is cut from the casting, using an elastic emery wheel. This operation must be carried out slowly, at the same time keeping the sample cool, as otherwise, the structure of the metal is likely to be modified. Numerous micro-examinations were necessary in arriving at the most suitable heat-treatment cycle. Now that this has been established, only an occasional examination is made as a check on operating conditions.

Tensile Tests

129. Tensile tests have occasionally been taken on the steel, and the results obtained compare very favorably with those from manganese steel produced in the basic electric furnace. The following are typical figures:

Maximum Stress, tons per sq. in.	65
Reduction of Area, per cent	42
Elongation on 2-in., per cent	64

Hardness Test

130. Samples from each heat of steel, after heat-treatment, are tested for Brinell hardness, and the test is carried out using a 3000 kg. load and 10 mm. ball. Care has to be taken in preparing the surface of the sample for the test, as due to decarburization, which occurs to a slight extent during heat-treatment, the skin of the casting becomes hard, and unless this is removed a high reading may be obtained. On the other hand, manganese steel hardens rapidly by cold work, and a hard skin may be produced in preparing the surface for the test. For these reasons, the use of any hardness measuring test which produces a relatively small impression will be likely to yield incorrect results. However, the hardened layer is only superficial, and, using the Brinell test with the heavy load and large ball, its effect is almost negligible. Correctly heat-treated manganese steel usually has a Brinell hardness number between 180 and 200.

ACKNOWLEDGMENTS

131. Under present conditions, the author is unable to mention by name those firms and gentlemen to whom acknowledgment

should be made for the part they played in the work described in this paper, but this omission will be rectified at the earliest opportunity. In the meantime, the author wishes to express his thanks to members of his staff who have assisted him in the preparation of this paper.

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DISCUSSION

C. W. BRIGGS¹ (*written discussion*): Mr. Gardom's paper is an interesting one in that it shows what can be done under the adverse conditions of locating melting capacity for the production of steel castings.

Mr. Gardom stated that he turned to the use of the cupola-converter process for the production of manganese steel, despite the statement that I had made at one time to the effect that the basic electric furnace is indispensable in the manufacture of manganese steel.

In the first place, I should like to alter my statement since Mr. Gardom and others, notably John Howe Hall, have shown that the basic electric practice is not indispensable. Manganese steel (12 to 14 per cent Mn) has been produced in the acid electric and the acid-lined converter for a number of years. John Howe Hall used the converter, at the Taylor-Wharton Iron and Steel Company, even before the last World War. Therefore, I wish to alter my statement to: "The basic electric method is the favorite way of making 12 to 14 per cent manganese steel."

The reader will note that Mr. Gardom used only a small portion of the gates, risers, skulls, and defective castings for scrap metal for his process. The remainder was sold to iron foundries for use to adjust the manganese content of the cupola mixture.

The loss of manganese content is quite high in the cupola-converter process; hence, manganese scrap can not be used economically and, for which reason, the basic electric method is favored. If one is in the position where it is not necessary that the foundry returns be used for economical reasons, then the plan, as outlined by Mr. Gardom, is quite acceptable.

¹ Technical and Research Director, Steel Founders' Society of America, Cleveland.

Fluoroscopic Examination of Light Alloy Castings

By A. E. CARTWRIGHT*, MONTREAL, CAN.

Abstract

This paper draws attention to the possibilities of direct visual X-ray examination of light alloy castings with the aid of a fluoroscopic screen. It is divided into three parts. Part One is a discussion of practicability and limitations of the method with quoted indications of its usage in Great Britain. Part Two is a description, with illustrations, of accessory apparatus evolved by a Canadian foundry for routine practice of fluoroscopic examination. Part Three indicates precautions and operational details necessary to attain, in this method, maximum possible sensitivity in detection of defects and concludes with a summarized opinion by the author, based on actual experience, of the advantages and economy of the judicious use of "screening."

Part I

INTRODUCTORY DISCUSSION OF EXISTING PRACTICES

1. Many interesting and useful papers have been published during the past decade relating to X-ray control and inspection of castings, with particular emphasis on the utility of the X-ray apparatus as a foundry control instrument. These papers have, on this continent, been devoted to the application and technique of X-ray examination by photography, which is termed "radiography." So far as the author knows, little use has been made in the United States and Canada of visual examination of castings by X-rays directed through a casting onto a fluorescent screen.

2. The use of the fluoroscopic screen is by no means uncommon for many other purposes, the most widely known use being that of shoe fitting. Most people have viewed the fitting of shoes on their feet by means of the low power, compact X-ray installations

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NOTE: This paper was presented at a session on Aluminum and Magnesium Castings at the 47th Annual Meeting, American Foundrymen's Association, St. Louis, Mo., April 29, 1943.

carried by many retail shoe stores. Fluoroscopic examination is also widely utilized for medical examinations, inspection of packaged foods to detect foreign inclusions, for fruit sorting, for checking mechanical assemblies and electrical parts, and by customs and other authorities to inspect packages, etc. Most thin, light metal and non-metallic objects may be explored non-destructively by fluoroscopic methods.

3. As applied to examination of castings for defects, it is of somewhat restricted value, owing to the limited sensitivity and contrast possible of attainment as compared with that obtainable by radiography. Sensitivity and contrast of a relatively high order are possible in radiography due to the fact that a registration of relative incident rays may be obtained by exposure of a film for a period of time. No such totalization of relative radiation transmission is possible in fluoroscopy, the image on the screen being almost instantaneous and non-cumulative. Furthermore, much greater potential is necessary in fluoroscopy to produce the required visible intensity on the screen than is required for radiography since, for the latter purpose, an image too dim to be seen on the fluoroscopic screen can be made legible on a film if projected for a sufficient length of time. Such increase of potential is also a powerful factor in reducing sensitivity. These considerations limit the use of fluoroscopy, so far as casting sections are concerned, to the light alloys of aluminum and magnesium, and, as mentioned above, in a definitely restricted scope even for these.

4. Several other factors aggregate to reduce sensitivity in fluoroscopic practice, some of which may be controlled to a degree to warrant the judicious use of the method, usually in conjunction with and supplementally to radiography.

5. Where fluoroscopy is feasible, it is obvious that some of the major items of cost of X-ray examination (films, chemicals, operator time) are avoided or reduced.

6. It is, as will be shown, a simple and inexpensive matter to arrange a fluoroscopic set-up in conjunction with and utilizing an X-ray installation already available for radiography.

7. With due consideration to the limitations of fluoroscopic practice, the author believes that the present discussion, description of operation, illustrations of apparatus, and of results obtained in the laboratories of the Robert Mitchell Co., Ltd., may be of interest and assistance to other foundry operators.

8. The fact that fluoroscopic examination of light alloy castings

is widely used in British practice will be a sufficient reason for quoting at some length certain references indicating the discretion applied there in its usage and the methods and equipment that have been evolved for the purpose. It was subsequent to consideration of these that our own design was planned and technique devised.

DISCUSSION OF BRITISH METHODS OF FLUOROSCOPY

9. Undoubtedly, primary consideration can be given, in referring to British practice, to the requirements and views of the British Air Ministry, Aeronautical Inspection Directorate, regarding inspection of castings by "screening," as the method is there referred to. A study of the extracts quoted from Inspection Instruction No. M 446, Part 3, 1940, paragraphs 20 to 23, will indicate the limitations and permissible utility of the method in their estimation:

"RADIOLOGICAL EXAMINATION OF CASTINGS"

"20. Where radiological examination is required, it is to be carried out in accordance with the following paragraphs, but it is to be borne in mind that the value of the examination may be reduced by failure to apply it properly, by unsuitable or defective apparatus and by lack of skill on the part of the operator. An inefficient examination may mean that defects, which should have been reported, escape discovery; in consequence, all radiological examinations must be carried out by a firm or a combination of firms who have been specially approved for this particular form of testing. Where circumstances render it desirable, such radiological examination may be carried out by the Aeronautical Inspection Directorate Test House on payment.

"21. There are two types of radiological examination:

"(a) By X-ray photography, which is referred to as radiography, and

"(b) By visual examination, using a fluorescent screen, which is referred to as screening. Radiography is a much more sensitive method of inspection than screening.

"Suitable castings may be examined by screening within the limits imposed by their size and shape, and with regard to the suitability of the X-ray equipment. Light alloy castings, having a maximum cross section of 2-in. in any part and

of such shape that manipulation will allow the X-rays to penetrate every part of the specimen so that a readable shadow is produced on the fluorescent screen, are suitable specimens for examination by screening. Steels, copper alloys and other heavy metals are, in general, unsuitable subjects for examination by screening. They must be examined radiographically where radiological examination is specified. Very minute flaws, such as intercrystalline porosity, cannot be detected with certainty by screening.

"23. It is to be clearly understood that screening cannot be regarded as acceptable where facilities are not available for moving the casting about in the X-ray beam, as efficient screening demands that the specimen be maintained in continuous movement while the fluorescent screen is carefully scrutinized. The specimen is to be manipulated by the use of tongs or a remote handling mechanism. The operator's hand must not be used for the purpose, whether enclosed in a protective glove or not. Care is to be taken during screening that the area of the screen illuminated is not excessive."

10. In Canada, radiological inspection of aircraft castings is technically controlled by the National Research Council, Ottawa, on behalf of the Royal Canadian Air Force and, while being basically similar to that of the British Air Ministry, does not include acceptance of castings by screening in any category or degree.

11. This does not preclude, of course, its use as a preliminary control method by the foundry, and it has been found extremely useful for this purpose and for pre-selection of castings for radiographic inspection.

12. The apparatus and methods evolved in England for screening practice have obviously been influenced primarily by the requirements stipulated in paragraph 23 of the Inspection Instruction above quoted. Several screening units are on the market there that emphasize the provision for "moving the casting about in the X-ray beam."

13. In the necessary preliminary studies made by us to evaluate the influence of viewing conditions, we came to the conclusion that the value of continuous movement of the type specified may, in general, be nullified by the lowering of definition brought about by necessarily having an excessive casting to screen distance. Much

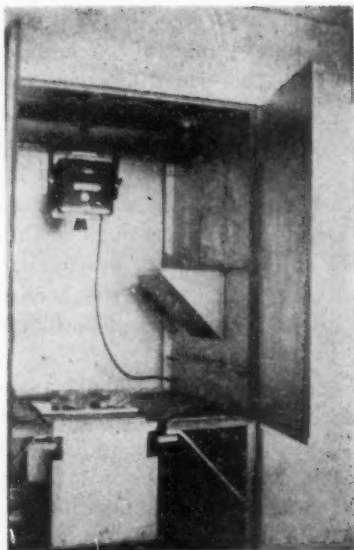


FIG. 1—SHOWING 85 KV. UNIT IN LEAD-LINED CABINET IN POSITION FOR RADIOGRAPHY.

better definition (and sensitivity) is obtainable by having the casting in closest proximity to the screen, supplemented by two or more views by directionally supporting the casting for completeness of examination, with lateral movement across the screen during the examination. Such a process lends itself readily to the conveyer belt type of operation on which our set-up is based.

DRAWBACKS OF SCREENING EQUIPMENT

14. The emphasis placed on movement of the casting in the beam by means of tongs or a remote handling mechanism has led to screening equipment designs having, in our opinion, serious drawbacks of the following nature:

- (a) Over-compression into minimum space.
- (b) Self-contained designs which leave no flexibility or adaptability of the tube for radiography.
- (c) Slowness of casting manipulation methods involving unnecessary time cost where quantity examination is a factor.
- (d) Long manipulation by the viewer is extremely awkward and fatiguing, the latter tending to decrease efficiency in viewing.

EXAMPLES OF SCREENING EQUIPMENT

15. Two most recent examples of screening equipment are described by Tunnicliffe*. One which he terms "of more conventional design" utilizes side ports for manipulation of the specimen by tongs and illustrates the indictment of slowness and operator fatigue made above. The other example is an invention by the author of the article, which he calls a "perspectrosphere." The views of this writer on fluoroscopy of castings include a description of his instrument, and, as they are very pertinent to this present discussion, are quoted herewith, while the original publication includes also photographic illustrations of both types of apparatus.

"While the greatest care is usually taken in radiography, screen examination is frequently undertaken in a very slipshod manner. This probably arises from the fact that specimens suitable for 'screening' are in a lower stress grade than those selected for radiography. On the other hand, since the flaw discrimination powers of the fluorescent screen are much



FIG. 2—SHOWING 85 Kv. UNIT IN LEAD-LINED CABINET IN POSITION FOR SCREENING.

* Tunnicliffe, E. J., "X-rays in the Light Metals Industry," *LIGHT METALS* (British), September, 1942.

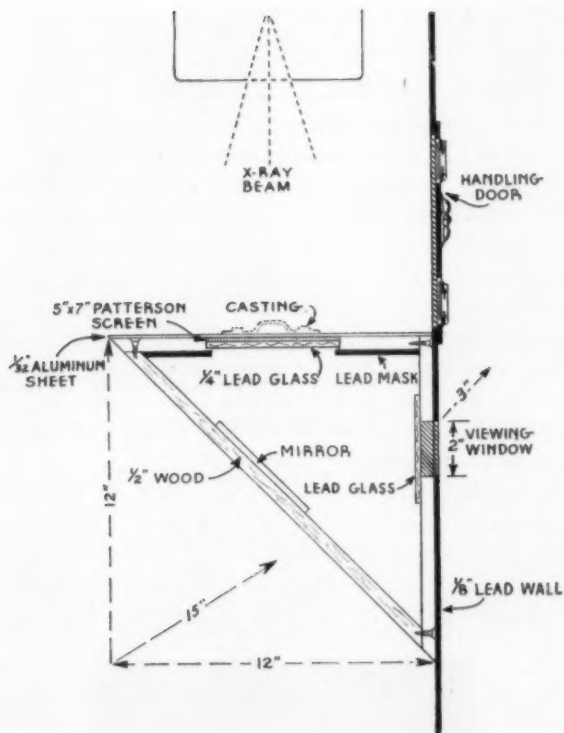


FIG. 3—SECTION OF SCREEN MIRROR HOUSING.

less than those of the film, correspondingly greater care should be taken. Under normal working conditions, the minimum discernible flaw size is in the order of 10 per cent. In some cases it may rise to a figure between 15 and 20 per cent. It has been the author's experience to find that, while the X-ray machine itself is most carefully selected, auxiliary screening equipment is almost invariably 'home made,' unsafe and inefficient. It is absolutely essential, for reasons to be examined later, that the screening apparatus be most carefully designed, constructed and used.

"The general design of the cabinet is governed, of course, by the average overall size of specimens to be handled in large quantities. Whatever the design, two extremely important features must be kept in mind; one, the provision of complete protection against radiation, and, second, the provision of

suitable holding devices to enable the specimen to be moved quite freely and without effort in several planes.

Arrangement of Screening Cabinets

"Various arrangements of screening cabinets have been designed, but it has almost invariably been necessary to sacrifice efficiency in inspection in order to obtain adequate protection. The main difficulties encountered are, (a) the necessity for handling specimens either directly or with tongs while wearing heavy lead-rubber gloves which rapidly deteriorate in protective value, (b) the very limited extent of specimen movement thereby obtainable, coupled with the necessity for shifting the specimens to uncover defects possibly being masked by the holding device, and (c) the physical and nervous fatigue resulting from handling hundreds of articles under conditions not conducive to comfort.

"Numerous attempts have been made to overcome these disadvantages. Conveyor belts have been used as also have rotating turntables. The great failing of arrangements of this type is that specimens are viewed in positions determined by their physical shape rather than in positions most suitable for

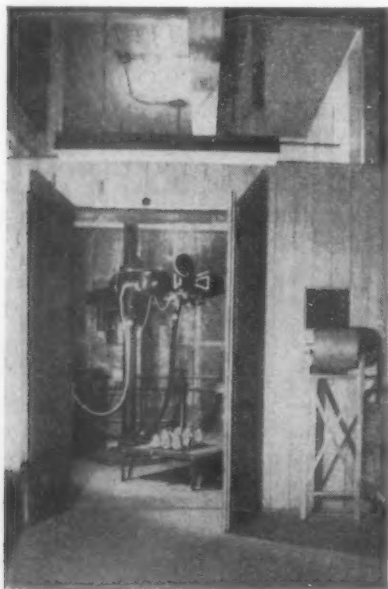


FIG. 4—SHOWING 220 KV. UNIT IN LEAD-LINED ROOM IN POSITION FOR RADIOGRAPHY.

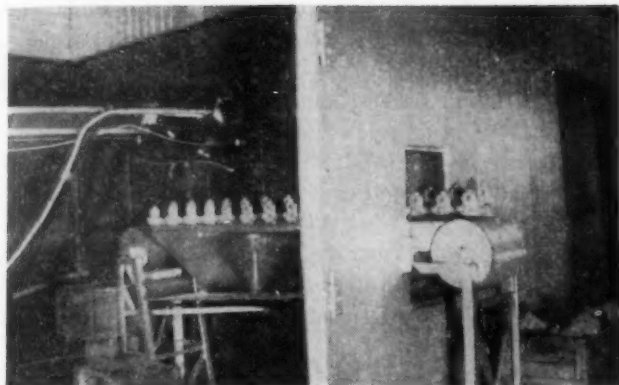


FIG. 5—INITIAL SCREENING SET-UP FOR 220 KV. UNIT.

X-ray examination. Carelessness on the part of the operator also becomes important since with a moving belt the recovery of specimens passed during a moment of distraction, due to no matter what reasons, becomes extremely irksome.

"With the object of overcoming these shortcomings, the author has developed a special machine, the 'perspectrosphere' . . .

"Referring to the three factors outlined earlier, the perspectrosphere (a) provides a remotely controlled spherical container for the specimen which, when the machine is in operation, is itself invisible and, therefore, does not cause masking, (b) enables the specimen to be rotated through 360° through every plane and to be retained in any desired position for more detailed examination or radiographing, and (c) greatly reduces fatigue as the specimen is not handled during operation and the operator can assume a comfortable position. A series of containers is provided for filling by a junior assistant and insertion in the machine. The operator's only effort is to control a footswitch and hand knob governing the movement of the specimen.

"The spherical container (in which the specimen is held between resilient cushions of ray-translucent material) is supported centrally by an electrically driven wheel which causes it slowly to revolve. Provision is made for rotating the driving wheel about its horizontal plane, thereby permitting the sphere to be, in effect, steered. Three sprung trunnions hold the container steady. The arrangement thus

permits a specimen to be oriented in any position relative to the tube-screen axis, the whole process being carried out in a ray-tight cabinet.

"In the cabinet the specimen is held in long tongs which protrude through annular openings provided with lead-rubber diaphragms. A very high degree of safety is obtained, provided the cabinet is well constructed and properly used.

"It will be appreciated that the numerous alternative types of screening cabinet cannot be dealt with here. However, X-ray equipment manufacturers are in a position to advise users on the choice of suitable types and to undertake their construction.

"All screening equipment should be periodically examined for defects through which pencils of primary or secondary rays might emerge, with consequent serious results. A very effective test devised by the author consists in using an illuminated electric lamp bulb as a specimen. If, on handling this specimen in the normal manner, it is possible to see escaping rays of light in a darkened room, then X-rays will escape in identically the same manner under operating conditions."

16. Certain of the impeachments made in this article are, in our experience, not fully warranted. If, for example, auxiliary screening equipment is "home-made," it need be neither unsafe nor inefficient. Lead sheet is quite cheaply available in any required thickness and easily workable for the construction of protective partitions or shields. The positioning of castings on a conveyor belt or turntable is not so limited in effectiveness as is implied,

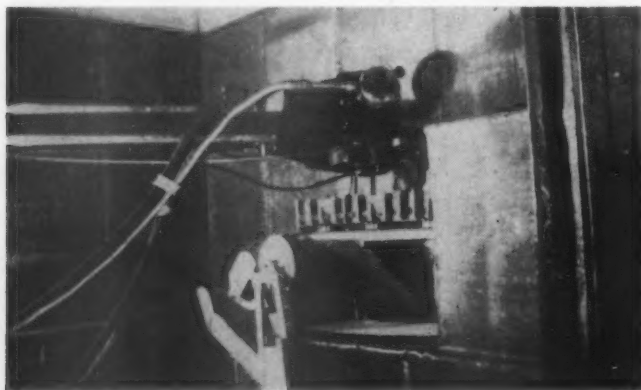


FIG. 6—LEAD TUNNELLING AND MECHANICAL RETURN BELT.

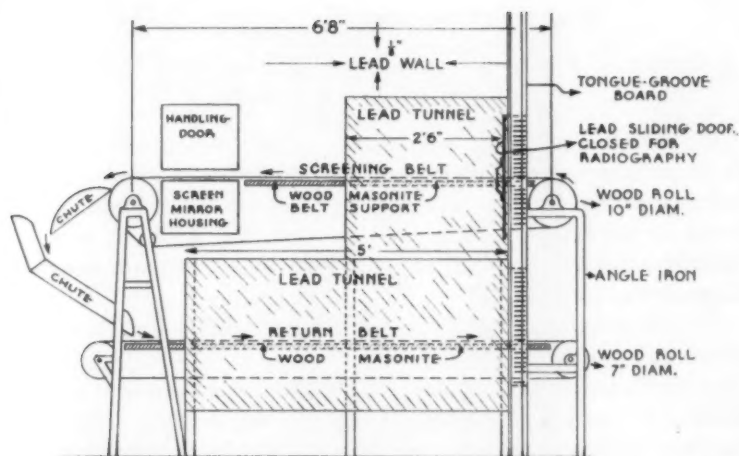


FIG. 7—BELT SCREEN EQUIPMENT ON 220 Kv. INSTALLATION.

particularly if more than one view of a casting includes even moderate ingenuity in the use of suitable supports to hold the casting at other angles in addition to that dictated by its physical shape. Then, if a travelling belt is operated by and at the will of the viewer rather than mechanically, the speed of movement forward and backward over the screen is readily controlled, and any distraction of the viewer can coincide with cessation of belt movement. In the design later described and illustrated these conditions have been given full consideration.

17. In connection with the spherical container of the "perspectrosphere," it is evident that, so far as focal conditions are concerned, no great advantage over handling by tongs is accomplished. It is obvious that only the generally impenetrable corners of a casting geometrically capable of contact with the inside of the sphere can be brought into reasonable proximity with the screen, while even greater restriction on the size and shape of the castings, adaptable to the container, is imposed than where handling by tongs is concerned. The acknowledged reduction in operator fatigue conditions would seem more logically attained by other means.

18. The maximum sensitivity of fluoroscopic examination obtained with the various designs of apparatus used is stated to be in the order of 10 per cent. This figure is corroborated by Low*.

* Low, K. S., *METALLURGICAL AND INDUSTRIAL RADIOLOGY*, Sir I. Pitman & Sons, England, 1940.

Part 2

A CANADIAN FOUNDRY'S DESIGN FOR FLUOROSCOPIC CONTROL OF LIGHT ALLOY PRODUCTION

19. Three years ago our laboratory was equipped with only an 85 kv. instrument, which was employed for radiographic control and inspection of aluminum and magnesium alloy castings produced by the foundry. Examinations were conducted by short exposures utilizing screen film with high speed calcium tungstate intensifying screens.

20. With this equipment, the maximum thickness of aluminum alloys that can be fluoroscopically examined is about $\frac{1}{2}$ -in., using near maximum potential of 85 kv. and 3 to 5 milliamperes current. Having a considerable quantity of castings coming within this limiting section thickness, we decided to add experimentally a fluorescent screen arrangement onto our existing radiographic set-up.

Arrangement of Equipment

21. Figure 1 illustrates the arrangement of the tube set-up for radiography. The original tube stand, supplied by the makers of the X-ray equipment for holding and positioning the tube, was not used. Instead, the tube head was mounted by means of a T fitting onto a horizontal bar in the top of the lead-lined cabinet illustrated. For fluoroscopic work, the tube is pushed along the bar to the right, over the screen housing, as shown in Fig. 2.

22. The screen housing, as sketched in Fig. 3, is simple in con-

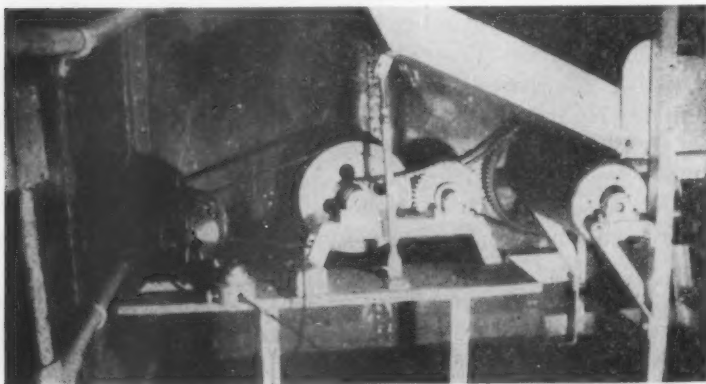


FIG. 8—SPEED REDUCTION DRIVE FOR RETURN BELT.

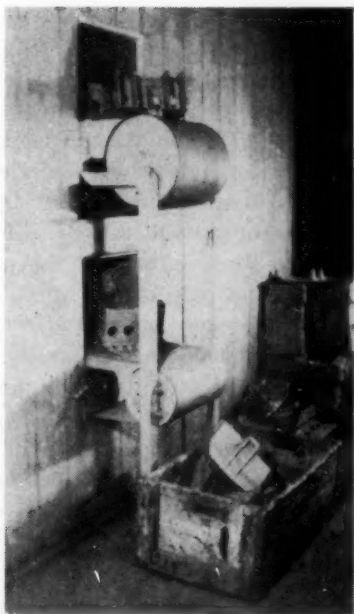


FIG. 9—PRESENT FEED END ARRANGEMENT WITH CASTING RETURN.

struction, made of wood. In the top horizontal surface is an open recess, accommodating a 5-in. x 7-in. fluoroscopic screen. The screen is covered by aluminum sheet $\frac{1}{32}$ -in. thick on which is placed the casting to be examined. The underside of the screen is covered by clear $\frac{1}{4}$ -in. thick lead glass. The screen is viewed indirectly by means of a surface-coated mirror (aluminized or rhodiumized) mounted at a suitable angle on the 45° back of the housing. The housing is mounted on the $\frac{1}{8}$ -in. thick lead wall of the cabinet, and a small window is cut in the lead wall. The window is also covered with $\frac{1}{4}$ -in. thick lead glass, fully protecting the viewer. A dark cubicle containing the controls also contains a leaded door, through which the viewer may alter the casting's position, or place another casting, during which operation he shuts off the X-ray emission.

23. The screen housing was positioned to a fixed focus screen distance of 12-in., as the minimum practical operating distance.

24. This arrangement was not meant to be more than exploratory and was, in fact, not convenient for examination in quantity for even those castings within the penetrating range of the tube. It did, however, furnish indications of the useful possibilities of fluoroscopic examination sufficient to warrant subsequent use of

it on higher power equipment and to suggest points of design for the larger scale equipment.

25. Though most screening units referred to in Part 1 utilize an X-ray tube of 140 to 150 kv. capacity and though this capacity is ample for radiography of aluminum and magnesium alloy castings of any usual size, our requirements included radiography of bronze and steel castings, in addition to that of light alloys. Therefore, we decided upon equipment of 220 kv. capacity.

26. The only possible disadvantage of this capacity is in the necessarily larger focal spot size of the tube, but this, we discovered, is not of serious consequence and affects in no noticeable degree the possible sensitivity obtainable in screening.

27. For convenience and flexibility, it is desirable to use the external transformer design of tube housing, utilizing shock-proof cable connections of the general type shown in our illustrations.

28. The 220 kv. equipment is installed in a lead-lined space 10 ft. sq., the walls, to a height of 9 ft., being of $\frac{1}{8}$ -in. sheet lead supported on a framework of 2-in. x 4-in. lumber. Being on the second floor of the building, the floor of the compartment is covered with $\frac{1}{4}$ -in. thick lead, over which is a soft wood flooring. Lead-lined doors include an automatic switch that cuts off the power from the tube should the doors be accidentally or purposely opened while the tube is operating.

29. Figure 4 illustrates this arrangement, with the tube in position for radiography, while Fig. 5 shows the preliminary arrangement of fluoroscopic belt and screen housing. The latter is essentially the same design as that used on the 85 kv. equipment except

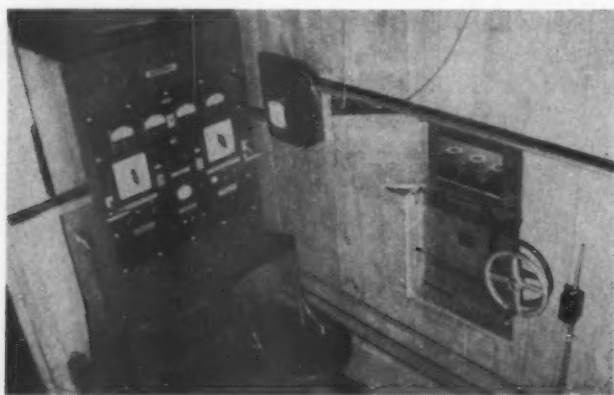


FIG. 10—CONTROL AND VIEWING COMPARTMENT FOR 220 KV. UNIT.

that an 8-in. x 10-in. fluoroscopic screen is used. The screen belt is of 3-ply interwoven cotton, one ft. in width, while the rolls are of wood, 10-in. in diameter and run on ball bearings. The later added return belt is similarly constructed. At this stage of construction, the screened castings were allowed to drop into a box which was emptied periodically during screening. Figures 6 and 7 illustrate the addition of a mechanically driven return belt for satisfactory castings. Faulty castings are pushed off the belt by means of a rake controlled by the viewer and these fall into a box placed parallel to the belt travel. Also shown is a lead tunnelling covering all the return belt and as much of the screening belt as practicable, in order to protect the person feeding castings onto the belt.

30. Figure 8 shows the driving mechanism with sprocket speed reduction from a $\frac{1}{4}$ h. p. motor. The fall of satisfactory castings is broken and guided by means of sheet metal chutes onto the return belt. Figure 9 illustrates the feed and discharge end of the present handling method.

31. Figure 10 illustrates the viewing-control booth. On the right is seen a hand wheel attached to the axis of the roller on the discharge end of the screening belt. The viewer manipulates this hand wheel to move the screening belt carrying the castings back and forth over the fluorescent screen. Immediately under the small handling door is seen the handle of the rake used to eject faulty castings. It is also used quite dexterously to change the position of a casting in the beam without opening the handling door and thereby shutting off the tube, as this door also has a safety switch, cutting off the current when it is opened.

Part 3

SOME CONSIDERATIONS AFFECTING SENSITIVITY OF FLUOROSCOPIC EXAMINATION

32. The sensitivity attainable, previously quoted at about 10 per cent, we find substantiated as an average, erring not greatly either in conservativeness or liberality.

33. Constant practice in conjunction with most favorable section thicknesses and strict compliance with ideal physical viewing conditions, will frequently result in sensitivity obtained down to 5 per cent or even less. The personal factor in screening is one of the most significant, and sensitivity obtained by one viewer may be greater or lesser than that possible for another.

Complete Darkness of Viewing Compartment

34. Probably the greatest essential to maximum results is complete darkness of the viewing compartment. Too great emphasis cannot be placed on this condition and all sources of light must be rigorously excluded, even those of low intensity that are contained in the control panel of the X-ray installation.

35. Where a degree of light is essential, it should emanate from a dull yellow-green source and be of approximately similar quality to the green fluorescence of the screen. This type of light should also be installed in the tube compartment so that when it is necessary for the viewer to open the handling door, he will not sacrifice his accumulated sensitivity to screening conditions.

36. Before screening is commenced, the viewer should spend at least five min. (preferably 10 min.) in the darkness of the viewing booth to condition his eyes to the work. He should lock himself in the booth, preventing thereby interruption and flooding in of light by opening of the door from a lighted exterior.

Additional Means of Improving Sensitivity

37. It is possible that additional means of improving sensitivity will be discovered as time goes on. We have considered various means of bringing about some improvement among which have been stopping down of the X-ray beam, the use of filters in the beam and the use of a lead mask 0.015-in. thick containing $\frac{1}{2}$ -in. slots evenly spaced and at right angles to the belt travel. None of these experiments met with sufficient success to warrant further study.

38. The thought behind the mask experiment was that the brightness of the 8-in. x 10-in. screen, if dimmed, except at the slots, might result in greater viewing sensitivity through the viewer being less influenced by the green brightness of the whole screen or that part of it not covered by the casting. In addition, the viewer would have his vision focused on a limited area of the image instead of having the entire casting to observe. The three slots were spaced so as to afford successively the total possible angle relation in the beam as the castings moved over the screen. Theoretically, this idea seemed to have possibilities for the betterment of sensitivity. Practically, like many another promising idea, it did not work out that way. Speed of examination was reduced which, in itself, was not entirely unexpected, or important if increased sensitivity resulted from the use of the mask. Very careful checking by different operators indicated fairly conclusive-

ly, however, that increased sensitivity was not obtained. A wedge penetrometer, as designed by the National Research Council, Ottawa, was used in this study. This penetrometer is an aluminum alloy wedge tapering from $3\frac{1}{2}$ -in. down to zero thickness containing 15 per cent, 10 per cent, 5 per cent and 2 per cent rectangular slots along its entire length. Potential and current are not of critically great importance over a certain minimum, which latter is about 140 kv. at 10 milliamperes. Greater range with not much lessened sensitivity is obtained by increasing potential toward the upper limit of 220 kv. except for sections under $\frac{1}{2}$ -in. thickness, when too great brilliance tends to lower sensitivity. Our efforts to determine definite optimum conditions of potential current distance thickness were not successful and resulted in some confusion of opinion, so that we came to the conclusion that, within the limits mentioned, each individual viewer should arrive at his own optimum.

39. Target-screen distance should be fairly small, good results being obtainable from 18- to 30-in. Greater distance than 30-in. does not, in our experience, increase sensitivity, while less than 18-in. is not very practicable from the mechanical standpoint of bulk of the tube housing and passage of average size castings under it.

Finding Defects by Fluoroscopic Examination

40. The type of defects most effectively discerned on the fluoroscopic screen are blow-holes, heavy metal inclusions and fairly heavy shrinkage defects.

41. Screening is, to date, ineffective for the detection of minute gas pockets of less than about 10 per cent of the section thickness and also for fine shrinkage, internal hot tears, pinhole porosity and small sand or slag inclusions.

42. It must, therefore, be used circumspectly for control or inspection purposes and supplemented by sufficient radiographic checks to preclude overlooking of the finer (though frequently just as serious) defects. The author does not advocate fluoroscopy for acceptance inspection except when in the most competent and conscientious hands. It is greatly inferior to radiographic inspection for all of the reasons noted and, above all, because of the absence of the tangible record provided by the radiographic film.

CONCLUSION

43. It is the author's hope that the above description will di-

rect the attention of many now equipped for and engaged in the radiographic control and inspection of light alloy castings, as well as those contemplating the installation of radiographic equipment, to fluoroscopic methods.

44. Radiographic control of foundry technique and radiographic inspection of aluminum and magnesium alloy castings has considerable advantage in low cost over that for the heavier metals, steel, iron, bronze, etc. Fluoroscopic examination, though of limited value, further reduces this cost factor in favor of the light alloys by savings in film and film processing costs.

45. The enormously expanded productive capacity for aluminum and magnesium metal, engendered by present war-time demands, will eventually result in large development of and encroachment by the light alloys in engineering and industrial uses previously filled by the heavier alloys. Lower strength ratios of the light alloys will be made much less significant by production control methods that will ensure unquestionable soundness of casting sections at much less cost than the equivalent control for the heavier metals.

46. For highly stressed aircraft castings, the maximum sensitivity obtainable by radiographic inspection is generally necessary and acceptance inspection by fluoroscopic methods of such parts is, as previously mentioned, highly questionable.

47. On the other hand, for unimportant low or non-stressed aircraft parts and for many industrial castings, the primary requirement is absence of gross defects, most particularly in machined locations, the great majority of which can be disclosed by screen methods. The reduction or elimination of machine shop losses possible by screen inspection of these types of aluminum and magnesium castings can conceivably pay the entire cost of an X-ray installation in a fairly short time, as well as providing a strong selling point for the light alloys and gaining for the organization that adopts this practice a name for reliably sound castings.

48. In our laboratory, where radiographic inspection involves examination of 400 to 1000 castings of many different designs daily, as much as \$15 to \$40 per day in film costs is saved by fluoroscopic elimination of castings containing major flaws, before proceeding with radiographic routine. Considering that the cost of the fluoroscopic accessories did not exceed about \$200 at an outside figure, this is well worth while.

DISCUSSION

Presiding: M. E. BROOKS, Dow Chemical Co., Bay City, Mich.

Co-Chairman: DR. N. E. WOLDMAN, Eclipse Aviation-Pioneer Instrument Div., Bendix Aviation Corp., Bendix, N. J.

CHAIRMAN BROOKS: This is an interesting presentation of a method of examination which apparently has been carried to much greater extent in England and Canada than here.

A. MORRISON¹ (*written discussion*): Mr. Cartwright, in addition to describing the equipment which he has used for fluoroscopy of light alloys, has pointed out the principal advantages and limitations of this method and has given details of the technique necessary to secure maximum sensitivity. A careful reading of his paper, particularly Part 3, will repay any who may be interested in this method of examination.

Where large numbers of similar and somewhat complex castings are to be examined, it may be desirable to build simple devices for rotating the casting slowly in the beam so that it can be seen from several angles. The reliability and sensitivity of examinations are considerably increased in this way.

LESLIE W. BALL²: Having studied the pre-printed version of this paper in some detail, I would like to make a few comments.

First of all, those of us who are interested in foundry progress, and in seeing innovations made, are very much indebted to Mr. Cartwright for his comprehensive contribution to American literature on non-destructive testing. It is interesting to note that this X-ray paper has been written, not by a theoretical physicist but by one of Canada's leading practical foundrymen.

In his conclusions, Mr. Cartwright expressed the opinion that use of fluoroscopy could improve the outlook of the light alloy industry and that it was a very useful weapon for meeting competition. I would like to stress that attitude very strongly. After approximately 6 years of experience in using X-ray as an aid to foundry work, I believe the job of X-rays is not to restrict or reject the foundryman's product; rather, it helps him evolve castings and to prove that they can be used where designers hesitate to specify castings.

As an example, in the aircraft industry, castings would be considered for certain jobs, but the specified safety factor was so high that the casting would be very heavy, and so the designers would find that they could do better with a built-up section or forging. X-ray has brought down the safety factor for aircraft castings from a figure of about 10 to about 2. Our aim is a safety factor of 1.4 for Class I aircraft castings that have been X-rayed, which means that castings can compete very strongly. Therefore, I hope that the days when the foundrymen regarded X-ray testing as an enemy have gone forever.

With regard to a few of the technical details: The sensitivity figures which Mr. Cartwright quoted, some of his own and some from outside sources, referred to a depth sensitivity of 10 per cent, meaning that the

¹ Radiology Section, National Research Council of Canada.

² Research Physicist, Triplett and Barton, Inc., Burbank, Calif.

cavity would have to occupy 10 per cent of the depth to be seen. In fluoroscopy the width sensitivity is also very important. For instance, cracks are not seen on the fluoroscope because they are so narrow that the X-rays going through them do not cover a complete fluorescent grain. The fluoroscopic screen consists of individual grains, and unless the defect is bigger than the "grains," we do not detect it.

Under certain conditions, Mr. Cartwright found that the focal spot size of the tube was not particularly important. I believe that this was because of the Robert Mitchell Company's arrangement. The casting is very close to the film and the defects are fairly large. I would like to ask Mr. Cartwright if he does not think that when the casting is far away from the film, the focal spots would have to be very small?

In reference to the machine, I think it is very good indeed. In my opinion, it is by far the best of those which have been described, particularly the close contact of the casting to the screen and the manual control in which the travel of the belt can be reversed.

I would like to add to Mr. Cartwright's lack of enthusiasm of the sphere arrangement. The light material, of which the sphere is made, is a very bad source of X-ray scatter. Those doing radiography will know that bakelite or any other radiographically translucent material, in the path of X-rays, is a very bad source of scatter, which, of course, reduces the sensitivity.

Also, there is a dangerous reference in the sphere paper to the use of a light bulb for testing the safety of the fluoroscopic cabinet. Protection of the personnel is very important but it cannot be achieved by means of a light bulb. Of course, painting the inside of the cabinet black, or putting black felt there, will stop light, although it absolutely will not stop X-rays. I would like to ask Mr. Cartwright what methods he uses and whether they have used films or other methods of testing for safety?

Then, there was a question of critical illumination. If the observer stays in the dark for 5 or 10 minutes, he is able to acquire the same ease of viewing at lower voltage and, consequently, the lower voltage gives a greater sensitivity.

Also, there was a reference to the use of slits to limit the beam. Now, viewing a fluoroscopic screen is something like viewing a film. You have to shade out the bright spots in order to see the dark spots. We had an experience in testing about 300 castings in which there was a flat plate with rather a deep rib. Without any precautions, the bright fluorescence under the flat plate made it difficult to see the darker shadow of the thick rib. In that case, the castings were immersed in carbon tetrachloride used in a tray and a great increase in sensitivity was obtained.

There was another point about the comfort of the operator, and that is air conditioning. I would like to ask Mr. Cartwright if he does not think air conditioning is a big help in maintaining the concentration of the observer?

Finally, I would like to say that I think Mr. Cartwright's perspective on screening is absolutely right and very accurately fits our own

experiences. He stressed the absence of a permanent record, which makes it essential to trust the operator. At present, in the United States, we have no system by which personal approval is given to radiographers, so we cannot go ahead and leave everything to the decision of the operator.

MR. CARTWRIGHT: I wish to thank Mr. Ball for his very kind remarks. At the same time, I would like to say that most of what I have learned about radiography, I have learned from Mr. Ball.

He obviously has read the pre-print to some purpose, and he has posed a number of questions that I do not like to take consecutively. I would like to have about a week to study them. I think the tone of the questions carries their answers pretty well, and I would answer in the affirmative to most of Mr. Ball's queries.

With regard to the focal spot size, as you will see from the paper, we started with an 85 Kv. installation, which has a much smaller focal spot than the 220. We collected castings with the defects which we examined on the screen, both the 85 Kv. and 220 Kv., and the difference in definition, as far as my eye and the eyes of the other operators were concerned, was not greatly different, so we assumed that the sensitivity of the method was too low to be affected by the size of the focal spot.

With regard to safety, our paneling in the booth consists of $\frac{3}{8}$ -in. lead, and I think I failed to mention in the paper that the lead is overlapped thoroughly in all directions so that it is almost impossible for the rays to penetrate. We have proved the safety of our booth by the use of small pieces of radiographic film which the operator had affixed to different parts of his body, from his head to his feet. We gave the maximum protection to the operator feeding the castings on the screen by means of the lead tunnel described in that paper. X-rays do get out of the tunnel, but there is no excuse for the operator being exposed very severely because he stands out of the direct line of radiation.

I suppose the longer an operator sits in the dark, the more ideally the screen is blocked and we could get greater sensitivity with lower voltage, had it not been our endeavor to obtain maximum sensitivity at the expense of practicability. We do screen a lot of castings, not just one or two, but such methods as individual blocking of castings, by means of carbon tetrachloride, are not workable in our case for rapid inspection work.

GERALD GOLDEN³: Mr. Cartwright spoke of 10 per cent sensitivity, based upon depth as a reference, but the density of the metal was not mentioned. How does this property enter into it? *

MR. CARTWRIGHT: The density of aluminum and magnesium are relatively the same as would be experienced in radiography.

MR. GOLDEN: You seem to base sensitivity on the fact that it is 10 per cent of the depth. How does the fact that one metal is denser than another affect sensitivity?

MR. CARTWRIGHT: The sensitivity of the examination is rather less for magnesium than for aluminum alloys, because of the lower ratio between the density of the void (air) and the density of the magnesium.

³ Hills-McCanna Co., Chicago, Ill.

than it would be respectively for the void in the aluminum alloys.

MR. GOLDEN: Specifically, over what range would it be practical to use fluoroscopic examination on magnesium alloys?

MR. CARTWRIGHT: I would not like to go beyond 2-in., the same as for aluminum. As I say, the sensitivity for the method is rather less for magnesium than it is for aluminum. The thicker you go, the less the sensitivity.

MR. GOLDEN: In other words, the density of the material does not play any part itself, it is the sensitivity of the field?

MR. CARTWRIGHT: Not greatly so, for fluoroscopic purposes.

MR. CARTWRIGHT (*Author's closure*): Both Mr. Ball and Mr. Golden in their remarks inferred that the percentage sensitivity referred to in the paper was not very clearly defined, therefore, I should like to emphasize that the term as used either for radiography or for fluoroscopy relates strictly to depth through a section and parallel to the X-ray beam. It does not apply either to percentage volume or to width at right angles to the X-ray beam.

Sensitivity in connection with the latter, for example, cracks of various widths, is governed primarily by the width of the crack and only secondarily by its depth parallel to the beam. As Mr. Ball points out, the extreme grain coarseness of the visual fluoroscopic screen renders detection of cracks narrower than the individual screen grains impossible, even though total depth of the crack may greatly exceed 10 per cent of the section thickness.

Where radiography is concerned, sensitivity to fine cracks is governed primarily by the focal spot size of the tube and further facilitated by critical softness of radiation, fine grain film, effective processing of the film, and ideal film viewing conditions. It is mainly for these considerations that we accord relatively small importance to the focal spot size of the tube for fluoroscopic work. Defect to screen distance in our practice is always at the minimum physically possible. If this distance is exaggerated unnecessarily and beyond a reasonable point, then, of course, definition will be reduced or destroyed not only by focal spot size, but also by projection blurring.

The necessarily coarse grain of the high illumination fluoroscopic screen is probably the limiting factor to improved definition and sensitivity for visual methods. We are studying, as are several others, the possibilities of a process intermediate between radiography and fluoroscopy which, already successfully practiced in the medical field, is referred to as fluorography. This consists of photographing a fluorescent screen image on miniature film, thereby overcoming several weaknesses inherent in fluoroscopy, among which may be mentioned lack of a permanent record, impracticability of relative fluorescent registration overcome by time exposure similar to radiography. Finer grained screens allowing of greater sensitivity through non-necessity for visual examination is also an anticipated advantage.

For commercial foundry control purposes, however, the author visualizes some reduction in radiographic practice from a successful development of fluorography rather than the opposite.

Temperatures Developed in Sand Cores During the Casting of Magnesium Alloys

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Abstract

In this paper, the authors present the need for development of a core binder to overcome the difficulties now experienced in casting magnesium alloys, because of inadequate core collapsibility. They present the primary problem as being the core knock-out operation. Special methods were found necessary in this operation. The use of pneumatic tools in core removal resulted in breakage of many thin section castings. Core collapsibility was found to be influenced by (1) temperature to which the core may be heated during the interval between pouring and knock-out, (2) length of time that the core remains at an elevated temperature, (3) atmosphere prevailing in the core during the period at which it is at an elevated temperature, and (4) composition of the core. Core temperature tests were made during the casting of magnesium alloys. Tests were also made, for purposes of comparison, during the casting of aluminum alloys, bronze, and gray iron. Heat content, by volume, of aluminum alloys at 1400°F., bronze at 2100°F., and gray iron at 2500°F. is 70 per cent, 190 per cent, and 290 per cent, respectively, greater than that of magnesium alloys at casting temperature at 1400°F. Temperatures developed in the cores of the magnesium alloy castings were found to be appreciably lower than those developed in the casting of aluminum, bronze, and gray iron. Length of time the core remains at an elevated temperature also was found to be much shorter in the case of magnesium. The authors stress the need for the development of a core binder which will break down at the low temperatures attained by cores, and the short time they remain at that temperature, during the casting of magnesium alloys.

INTRODUCTION

1. The magnesium foundry industry has been continually confronted with the problem of inadequate core collapsibility. This has resulted in the loss of castings by hot tears, but the primary difficulty is with core knock-out. Special methods of core removal,

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such as soaking in hot water followed by water sand blast; heat treating prior to core removal; or use of pneumatic hammers and chisels have been necessary. Core removal by the use of pneumatic tools has been necessarily so severe that many castings of thin section have been broken.

2. Core collapsibility is influenced by four predominant, inter-related factors, namely:

- (1) The temperature to which the core may be heated during the interval between pouring and knock-out.
- (2) The length of time that the core remains at an elevated temperature.
- (3) The atmosphere prevailing in the core during the period at which it is at an elevated temperature.
- (4) The composition of the core.

3. The aims of this paper are (1) to indicate the range of temperatures developed in baked, oil-sand cores during the casting of a magnesium alloy, the length of time, and the atmosphere prevailing in the core during the period at an elevated temperature, and (2) to make a comparison with other commonly cast metals.

4. It is believed that this information will be of value to producers of core binders by pointing out some of the requirements of a suitable core binder for the magnesium foundry industry.

SCOPE

5. The first tests were made with magnesium alloys. Subsequently, to provide a more complete background, core temperatures were measured under similar conditions during the casting of aluminum alloys, bronze, and gray iron.

6. The choice of test cores and castings was dictated by conditions prevailing in magnesium foundries today. Most of the castings produced are for aircraft, where light weight and strength are paramount considerations. This has placed emphasis on thin sections. The average section thickness of magnesium castings is less than $\frac{1}{2}$ -in., with $\frac{1}{4}$ -in. common, and 1-in. considered heavy. Since internal cores provide the greatest difficulty in knock-out, a cylindrical core of 3-in. diameter and 8-in. length was selected. Hollow cylindrical castings of $\frac{1}{4}$, $\frac{1}{2}$, and 1-in. wall section then were cast around the core. Temperatures of the core were measured at distances of $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$, and 1-in. from the core surface. Aluminum, bronze, and gray iron castings of 1-in. section were

cast around similar cores and temperatures were measured.

7. After obtaining the average maximum core temperatures developed during the casting of the above alloys in 1-in. section, tests were conducted on 2-in. diameter test cores to determine their rate of heating at the core center. Core collapsibility (retained strength at room temperature) was measured by heating test cores at elevated temperatures in oxidizing and non-oxidizing atmospheres.

8. An explanation of why the retained strength at room temperature was studied rather than strength tests at an elevated temperature, is in order. The problem of excessively high strength at both elevated and room temperature exists. However, high strength at room temperature is the major consideration in our foundry. It may be true that means for reducing the retained strength will aid in reducing the high temperature strength.

LITERATURE REVIEW

9. In view of the large amount of work done on the high temperature properties of core and molding sands, it is disappointing to find that there is little published information on the measurement of core temperatures during the casting period. Scott¹ compares the maximum temperatures developed in core sand, and dried and green molding sand during casting of gray iron, finding them to be 1750, 1840 and 1750°F., respectively, at points $\frac{1}{2}$ -in. from the mold surface. Dierker² and Maske and Piwowsky³ measured mold temperatures during the casting of steel and gray iron. Briskin⁴ recently has stated that in a thin-walled magnesium casting, the core temperature at $\frac{1}{8}$ -in. from the surface may not exceed 500°F.

10. A compilation of thermal data for the more common casting metals and principal alloying elements is shown in Table 1 on both a weight and volume basis. The values for density, specific heat, heat of fusion, and heat content for the pure metals and alloying elements are from the *Metals Handbook*⁵. Kelley⁶ is the authority for the specific heat values for liquids. The heat of fusion values for magnesium are those published by Kelley⁷ and those contained in the data book⁸ published by the company with which the authors are associated. The heat content values are stated for definite temperatures and are derived either by interpolation or by computation using the liquid specific heat.

11. Magnesium and aluminum often are compared. Both are

¹ Superior numbers refer to bibliography at end of paper.

Table 1
THERMAL DATA FOR CAST METALS†

Element	Density ⁵ Gm./cm. ³ Lb./cu. in.	Specific Heat ⁵ , θ , s ($\frac{\text{Cal.}}{\text{gm.}}/^\circ\text{C.}$) Liquid ⁵	Heat of Fusion ⁵ , s		Temp., $^\circ\text{F.}$	Heat Content ⁵ , s		Ratio ⁵
			Cal./gm.	B.t.u./Lb.		Cal./gm.	B.t.u./Lb.	
Magnesium	1.74	0.0628	88.8	159.8	1400	255.5	460.0	28.9
Aluminum	2.7	0.0975	93.0	167.4	1400	286.0	515.0	50.2
Copper	8.94	0.323	50.6	91.0	2100	169.5	305.0	72.8
Iron	7.87	0.284	65.0	117.0	2500	221.5	398	98.6
Zinc	7.14	0.258	0.09	24.09	1400	108.8	195.8	113
				at 1400°F.	2100	158.3	285.0	50.5
Manganese	7.44	0.268	64.8	116.64	1400	121	216.0	73.5
Silicon	2.4	0.087	337.57	607	2500	302	543.0	58.0
Tin	7.3	0.264	14.4	25.9	2500	292.5	526.0	145.5
Carbon	2.22	0.0802	0.0556	—	2100	79.0	142.0	45.8
Lead	11.34	0.409	6.26	11.27	2500	533	960.0	37.5
					2100	43.4	78.2	76.8
Alloys								32.0
Mg—91.0%								
Al—6.0%	1.83 ^s	0.066 ^s			1400	252	454	58.0
Zn—3.0%								145.5
Al—95.7%	2.77 ^s	0.100 ^s			1400	279	502.5	45.8
Cu—4.3%								37.5
Cu—79.4%								76.8
Pb—12.0%	8.9 ^s	0.322 ^s			2100	152.5	275	78.2
Sn—7.6%								32.0
Zn—1.0%								
Fe—94.7%					2100	152.5	275	58.0
Si—1.88%	7.3 ^s	0.264 ^s						145.5
C—2.89%					2500	232	418	45.8
								37.5
								76.8
								32.0

^s Assuming the heat content of pure magnesium to be 100.

[†] Superior numbers refer to bibliography at end of paper.

classed as light metals, have approximately the same melting points, and have similar pouring temperatures. At 1400°F. , on a weight basis, aluminum has a heat content above 32°F. of 515 B.t.u. per lb., as compared to 460 B.t.u. per lb. for magnesium. In a casting, however, comparison must be made on a volume basis. A major difference now shows up, with aluminum having 50.2 B.t.u. per cu. in. compared to 28.9 B.t.u. per cu. in. for magnesium at the same temperature. *At 1400°F. , aluminum has 73 per cent more contained heat than magnesium on the basis of equal volume.*

12. The heat content values for alloys have not been published. However, it is stated in the *Cast Metals Handbook*⁹ that the specific heat of cast iron can be assumed as the average of its constituents. Carrying this a step further, it may be assumed, for all practical purposes, that the heat content of an alloy is the sum of the heat contents of its constituents. (This assumption is not fully accurate since the formation of metallic compounds, and other structural changes within the alloy, will alter the heat content.) Lacking more accurate data and methods, the heat contents of four alloys were calculated (Table 1). *Here again the heat content of the aluminum alloy containing 4.3 per cent copper at 1400°F. , on a volume basis, is 67.5 per cent more than the magnesium alloy with 6 per cent aluminum and 3 per cent zinc.* The heat content of bronze at 2100°F. and of gray iron at 2500°F. is much higher than either magnesium or aluminum. Bronze contains 187.5 per cent and gray iron 268 per cent more heat at their respective pouring temperatures than the previously mentioned magnesium alloy at 1400°F.

13. Returning to a comparison of the magnesium and aluminum alloys, even though pouring temperatures are similar, the large difference between heat contents leads one to expect a significant difference in the mold and core temperatures when those alloys are poured into similar molds. However, the actual core temperatures cannot be calculated accurately from the data available. Actual temperature measurements in various parts of the core must be made to obtain accurate data.

TEST PROCEDURE

14. The cores used in the tests were made from an oil-sand core mixture, using a bank sand of 65 A.F.A. Fineness Number containing about 0.5 per cent A.F.A. clay substance as the base. The binder consisted, by weight, of 1 per cent core oil, 0.3 per cent corn

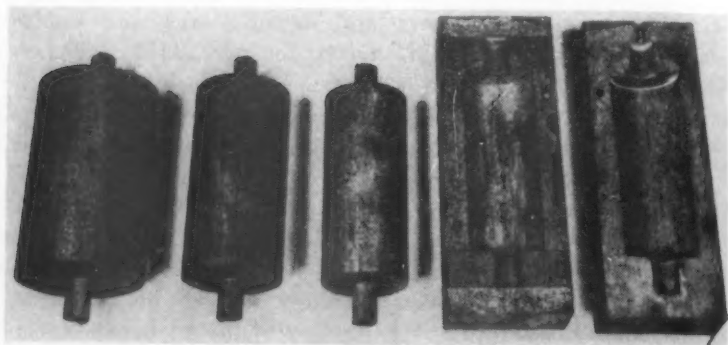


FIG. 1—CORE BOX AND PATTERNS USED TO MAKE TEST CASTINGS.

flour, and 0.35 per cent dextrin. Sulphur and boric acid, in the amounts of 0.75 and 0.50 per cent respectively, were added as protective agents. The sand was mixed in a 24-in. diameter laboratory-size, muller type mixer. The core sand properties are shown in Table 2. The term "sand agents" is commonly used in magnesium foundries to describe a number of chemicals, principally of the sulphur, boron, and fluoride groups. When added to molding or core sands in small amounts, they are of benefit in preventing the

Table 2
CORE AND MOLDING SAND PROPERTIES

SCREEN ANALYSIS			MIXTURES		
	Core Sand	Molding Sand		Core Sand Parts by Weight	Molding Sand Parts by Weight
A.F.A. Fineness Number	63.5	94.0	Bank Sand	100.0	92.0
Distribution Number	118	78.4	Bentonite	—	4.0
A.F.A. Clay Substance, per cent	0.6	0.5-1.0	Sulphur	0.75	0.3
	Sub-Angular	Sub-Angular	Boric Acid	0.50	0.5
Grain Type			Ammonium Silco-fluoride	—	3.2
On Mesh No.			Cereal	0.30	—
12	—	—	Dextrin	0.35	—
20	0.8	—	Core Oil	1.25	—
30	1.6	—	Water, per cent	6	4.0
40	6.8	0.2			
50	18.0	0.6	Properties		
70	27.4	4.4	Moisture, per cent	6.05	3.95
100	27.4	37.8	Green Permeability	70	73
140	11.4	39.0	Green Compression, psi.	0.75	7.2
200	5.2	17.2	Green Shear, psi.	—	1.8
270	0.4	0.6	Deformation, in. per in.	—	0.019
Thru 270	0.4	0.4	Tensile Strength, psi.	135	—
	99.4	100.2	Dry Permeability	180	—
			Dry Compression, psi.	1600	62

reaction of chemically active magnesium with oxygen present in the mold, either as a constituent of air, water, or sand.

15. Figure 1 illustrates the core box and patterns used in making test castings. The cores were made in halves. Perforated lengths of $\frac{1}{8}$ -in. diameter pipe, each containing four, 24-gauge, iron-constantan, glass-insulated thermocouples, were placed in the drag half of the cores. The thermocouples branched out at the center of the pipe with two projecting to each side. The thermocouple ends were located accurately at distances of $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$, and 1-in. from the surface of the core and $\frac{1}{8}$ -in. below the parting line. The cores, including thermocouple assembly, were baked for 2.5 hours at 400°F . Following baking and cooling to room temperature, the halves were carefully cleaned, pasted together, and dried. Next, the joints were smoothed with a daubing mixture, the cores heated for 5 min. at 350°F ., and a protective spray applied. The cores

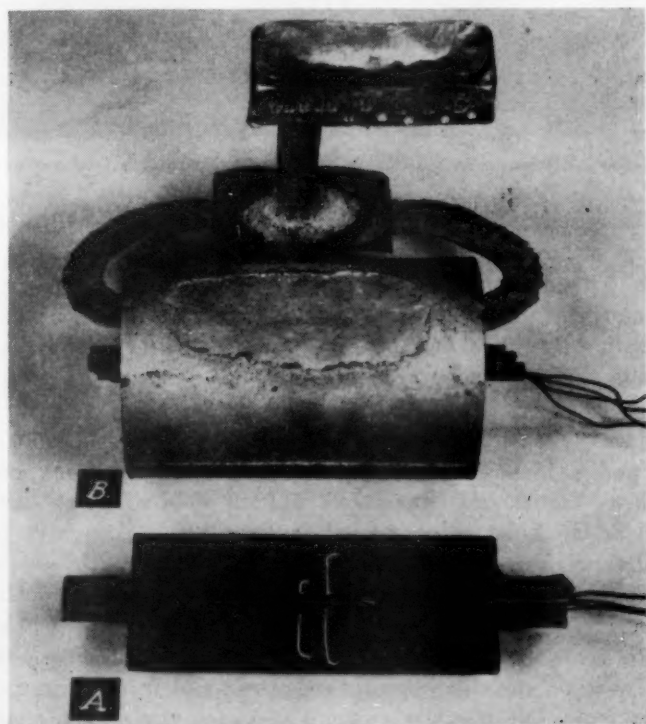


FIG. 2—A—DRAG HALF OF A CORE SHOWING POSITION OF THERMOCOUPLES. B—TEST CASTING SHOWING LOCATION OF SPRUE AND GATES.



FIG. 3—ARRANGEMENT OF MOLD AND POTENTIOMETERS FOR OBTAINING CORE TEMPERATURES.

were now ready for the mold. A drag half of a core, with thermocouples in position, is shown in Fig. 2-A.

16. The molding sand was mulled thoroughly and then aerated. The moisture was controlled between 3.95 and 4.05 per cent in the realization that a variation could alter the cooling rate of the casting and the core temperatures.

17. The split pattern was molded in a 10 x 16-in. snap flask. Care was taken by the molder to maintain a uniform mold hardness and uniform location of pattern in flask from one mold to another. The casting was gated at both ends with the sprue located at one side, as illustrated in Fig. 2-B. Skim gates (metal screens) were used on all magnesium and aluminum castings, but no skim cores or screen were used on either the gray iron or bronze castings. The cores were inserted into the mold so that the thermocouples which were $\frac{1}{8}$ and $\frac{1}{4}$ -in. respectively from the core surface, were on the side opposite the sprue and in the drag portion of the mold. No risers were employed. On closing the mold, the snap flask was removed and replaced with a steel jacket. The mold was then placed on the pouring floor and projecting

thermocouples were connected to four portable potentiometers, as shown in Fig. 3. The mold was now ready for pouring.

18. The alloys were melted in gas-fired melting units. The magnesium alloys were melted in steel crucibles under a proper flux and heated to a pouring temperature of 1400°F. The aluminum, bronze, and gray iron alloys were melted in silicon carbide crucibles. The analyses and pouring temperatures of the alloys are shown in Table 3. With the exception of the gray iron, metal temperatures were measured by a temperature indicator connected to an 18-gauge, chromel-alumel thermocouple protected by 1/4-in. diameter steel tube. The iron temperature was measured by an optical pyrometer focused on the metal stream as the mold was poured. Temperature readings were taken with each thermocouple, starting when the casting was poured, and continuing for a sufficient length of time to get a complete picture of the core temperatures.

TEST RESULTS

19. Figures 4 to 9 show the time-temperature relations for each of the four points in each core as the various alloys were cast. The time scale is constructed on a logarithmic basis to provide expansion for the first portion of the curve, which proves the most interesting.

20. Figure 4 represents a 1-in. section of gray iron poured at

Table 3

COMPOSITION AND POURING TEMPERATURE OF ALLOYS TESTED

<i>Alloy</i>	<i>Composition, per cent</i>	<i>Pouring Temp., °F.</i>	<i>Initial Core Temp., °F.</i>
Magnesium	Aluminum 6	1400	95
	Zinc 3		
	Manganese 0.15		
	Magnesium Remainder		
Aluminum	Copper 4.3	1400	82
	Aluminum Remainder		
Bronze	Copper 79.4	2100	91
	Lead 12.0		
	Tin 7.6		
	Zinc 1.0		
Gray Iron	Total Carbon 2.89	2460	89
	Combined C 0.75		
	Silicon 1.88		
	Manganese 0.53		
	Sulphur 0.065		
	Phosphorus 0.45		

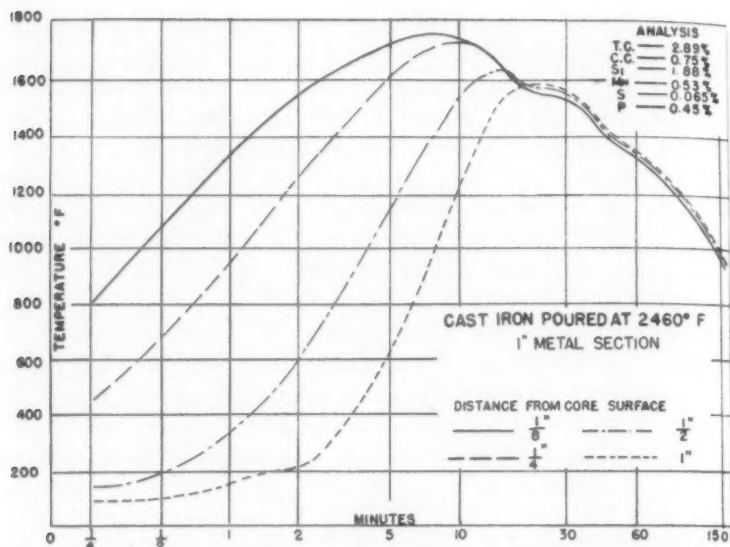


FIG. 4—TEMPERATURES DEVELOPED IN CORE FOLLOWING CASTING OF 1-IN. SECTION GRAY IRON TEST CASTING.

2470°F. The shell of the core heats very rapidly so that, within 15 sec., the sand $\frac{1}{8}$ -in. from the core surface is above 800°F. and rapidly rises to a maximum of 1760°F. after 8 min. The interior heats much slower, showing an arrest at approximately 200°F., then rapidly rises to a maximum of 1570°F. after 25 min. The cooling from the maximum core temperature is very slow, requiring more than two hours to drop to 930°F.

21. The appearance of a thermal arrest at 200-220°F. is a characteristic of all the thermocouple positions but is more pronounced at the interior. The explanation may be that the baked cores contained an appreciable amount of water, even though they were used within a few hours after baking and warmed just prior to inserting into the mold. This moisture may be vaporized at the core surface by the hot metal and driven into the interior where it is condensed. After a short period, moisture may collect in the interior of the core so that, when this part of the core does finally get heated to the boiling point of water, enough water has collected to produce a considerable arrest.

22. Figure 5 shows the core temperatures for a 1-in. section bronze casting. They are very similar to the curves for cast iron but do not reach as high a temperature. The maximum at $\frac{1}{8}$ -in. from the core surface is 1425°F. reached after 7 min. The interior

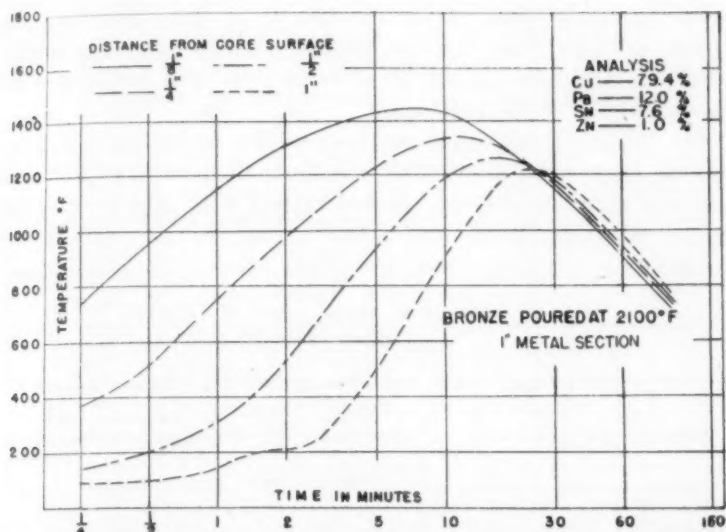


FIG. 5—TEMPERATURES DEVELOPED IN CORE FOLLOWING CASTING OF 1-IN. SECTION BRONZE TEST CASTING.

reaches a maximum of 1210°F. after 25 min. and then falls to about 740°F. after 100 min.

23. The aluminum alloy (1-in. section) in Fig. 6, shows a much

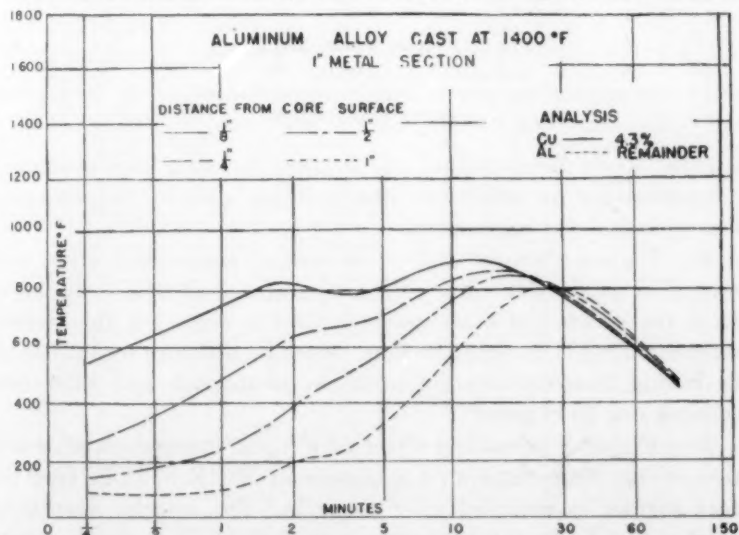


FIG. 6—TEMPERATURES DEVELOPED IN CORE FOLLOWING CASTING OF 1-IN. SECTION ALUMINUM TEST CASTING.

lower maximum than either the bronze or gray iron, reaching 905°F. at $\frac{1}{8}$ -in. from the core surface after 14 min. The interior reaches a maximum of 810°F. after 25 min. The entire core was above 650°F. for about 50 min.

24. Figure 7 shows the core temperature on casting a 1-in. section of magnesium alloy. The maximum temperature $\frac{1}{8}$ -in. from the core surface is 800°F., reached after 2 min. The interior does not even reach 650°F., but 600°F. after 25 min. This is only

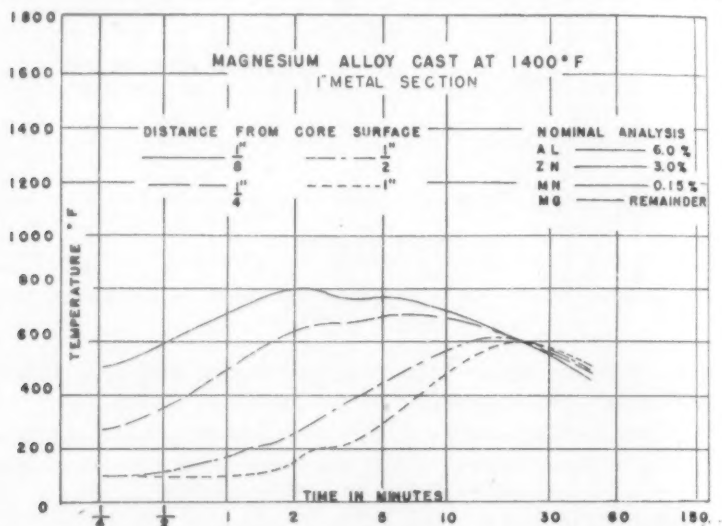


FIG. 7—TEMPERATURES DEVELOPED IN CORE FOLLOWING CASTING OF 1-IN. SECTION MAGNESIUM TEST CASTING.

slightly above the operating temperature for some core ovens and a temperature at which oil cores collapse slowly. *Yet this is a heavy section for magnesium.*

25. Figure 8 shows a $\frac{1}{2}$ -in. section of magnesium alloy, cast around a core. Maximum core temperatures of 615°F. at $\frac{1}{8}$ -in. from the core surface are reached after 2 min., but the interior reaches only 435°F. after 15 min. Much of this core never gets up to baking temperatures employed in production and little core collapse can be expected.

26. Figure 9 shows the effect of a $\frac{1}{4}$ -in. magnesium alloy section on core temperatures. A maximum of 530°F. at $\frac{1}{8}$ -in. from the core surface is recorded after one min. The interior eventually reaches 340°F. In this case, only a shell about $\frac{1}{4}$ -in. thick around the core reaches even the core oven temperatures employed in

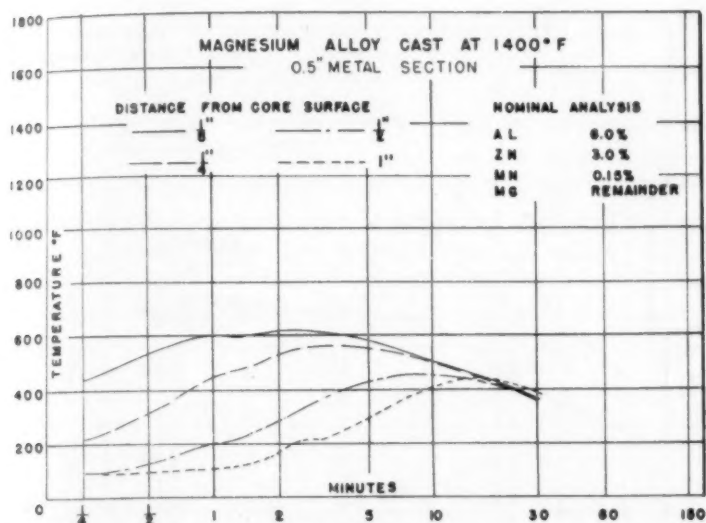


FIG. 8—TEMPERATURES DEVELOPED IN CORE FOLLOWING CASTING OF $\frac{1}{2}$ -IN. SECTION MAGNESIUM TEST CASTING.

baking the core during its production cycle.

27. It is interesting to note that the curves in Figs. 4 to 9 cross each other. The exterior of the core, initially at a higher tempera-

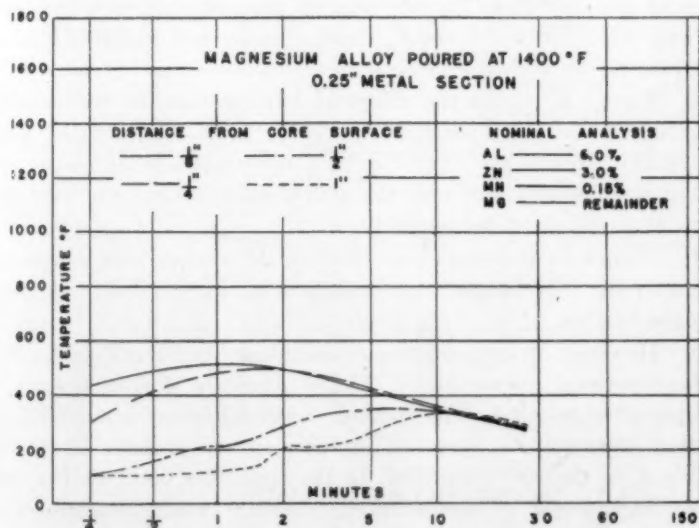


FIG. 9—TEMPERATURES DEVELOPED IN CORE FOLLOWING CASTING OF $\frac{1}{4}$ -IN. SECTION MAGNESIUM TEST CASTING.

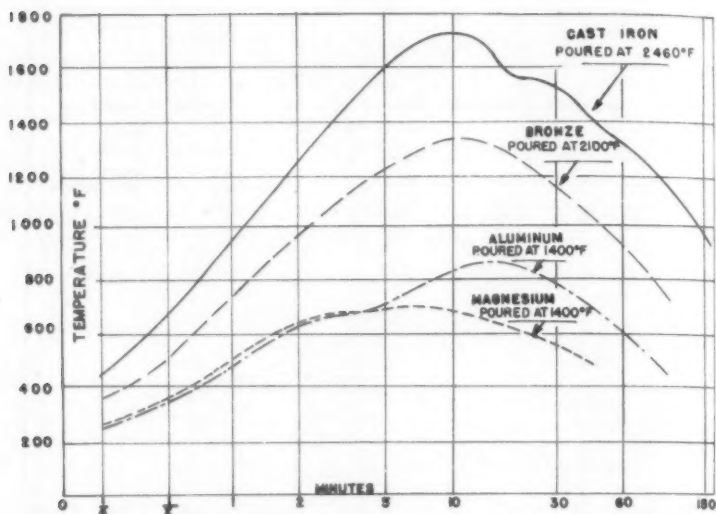


FIG. 10—COMPARISON OF TEMPERATURES GENERATED $\frac{1}{4}$ -IN. FROM THE CORE SURFACE WHEN VARIOUS METALS ARE POURED INTO 1-IN. SECTIONS AROUND THE CORE.

ture than the interior, finally becomes cooler than the interior. The heat stored up in internal cores can be partially dissipated by the loss of hot gases to the atmosphere. However, most of the heat is stored and can make its exit only by passing back into the casting and thence into the mold, which absorbs and radiates it at a slow rate to the atmosphere.

28. Figure 10 shows the effect of 1-in. sections of the various alloys on the core temperatures at $\frac{1}{4}$ -in. from the surface. This graphically depicts the very low core temperatures developed on casting magnesium, and also the much shorter time the core remains at an elevated temperature.

29. Figure 11 indicates the effect of the various cast alloys on the maximum core temperatures reached at various distances from the core surface.

30. However, in actual practice cores may not reach or remain at these elevated temperatures. Molds often are shaken out a few minutes after pouring. The casting then rapidly loses much of its residual heat to the surrounding atmosphere instead of transferring it to the core. Further, in the case of a mold shaken out early, the transfer of heat from the casting to the atmosphere is much more rapid than the transfer of heat from the casting to the mold and then to the atmosphere. As a result, the cores in such

castings lose their residual heat faster and remain at elevated temperatures for shorter periods of time.

CORE COLLAPSIBILITY

31. In any consideration of heat content and collapsibility, it must be realized that the heat content *above* the temperature at which collapsibility of the core occurs is the important thing. For example, assume that a core begins to rapidly collapse at 650°F. Any metal poured against this core at temperatures below 650°F., regardless of the quantity of heat contained, would not cause any

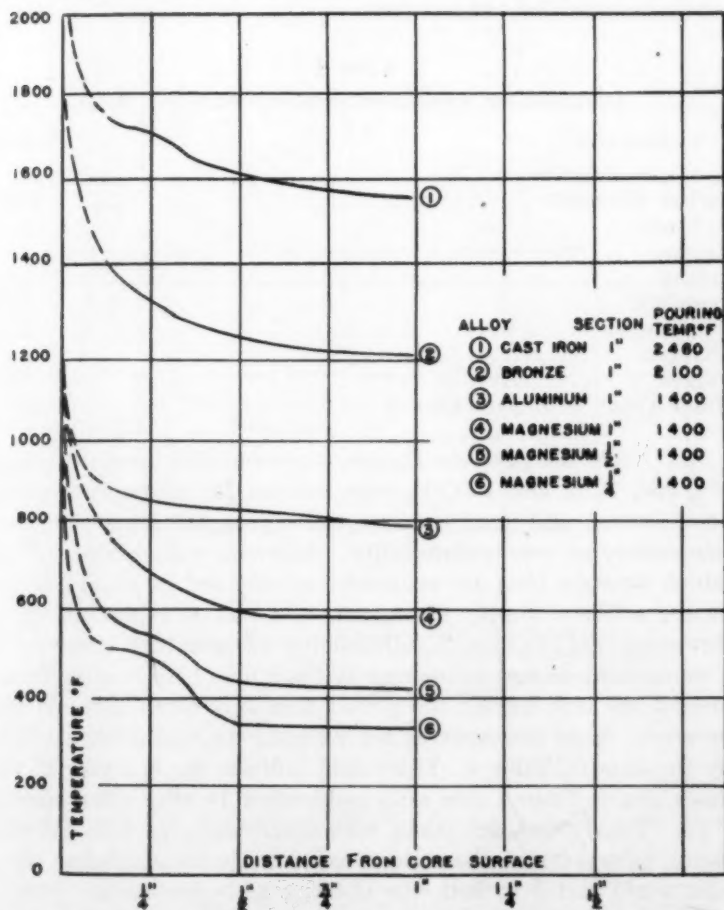


FIG. 11.—TEMPERATURES GENERATED AT DISTANCES OF $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, AND 1-IN. FROM THE CORE SURFACE WHEN VARIOUS CAST METALS ARE POURED INTO SECTIONS OF DIFFERENT SIZES.

appreciable collapse of the core. It is the amount of heat in the metal above the collapsibility range, combined with pouring temperature of the metal, that determines to a marked extent the collapsibility to be expected of a core. That is, collapsibility is accelerated with increase in temperature above the collapsibility range, and it is to be expected that of two metals with the same heat content above the collapsibility range, the one with the higher pouring temperature would provide the greater core collapsibility. It should also be considered that every core composition has its own collapsibility range and that no one basic temperature range can be assigned for test purposes.

Table 4
ANALYSIS OF VENT GAS FROM CORE SAND MOLD

<i>Composition</i>	<i>Per Cent</i>
Hydrogen Sulphide	18.0
Carbon Monoxide	16.8
Hydrogen	6.5
Methane	2.0
Ethane	4.3
Propylene	2.6
Ethylene	1.4
Nitrogen	13.1
Oxygen	2.8
Water Vapor + Sulphur Dioxide	32.5

32. From the previous figures, representative temperatures of 650, 850, 1275, and 1650°F. were selected for magnesium, aluminum, bronze, and gray iron respectively as being suitable for a comparison of core collapsibility. Although collapsibility or retained strength tests are ordinarily carried out in an atmosphere having a liberal supply of oxygen, it is well to repeat an earlier statement that the rate of collapsibility of most core binders is to a considerable extent influenced by the atmosphere existing in and around the core during the period that it is at an elevated temperature. Mold atmospheres are reducing in character, as shown by the data in Table 4. These data indicate the analyses of vent gases issuing from a core sand mold taken 15 min. after pouring.

33. Precautions are taken with magnesium, as with no other metal, to make sure the mold atmosphere is non-oxidizing. Sand agents are added to both the molding and core sands. Some of these are reducing agents. Again, it is not uncommon practice to flush the molds with sulphur dioxide gas. Consequently, it is to

be expected that magnesium mold atmospheres are less oxidizing in nature than those encountered with other alloys. These considerations led to the testing of core collapsibility in both oxidizing and non-oxidizing atmospheres.

34. It was first thought necessary to determine the times required for the center of the test core to reach an equilibrium with the furnace temperature. Test cores, 2-in. diameter by 2-in. long,

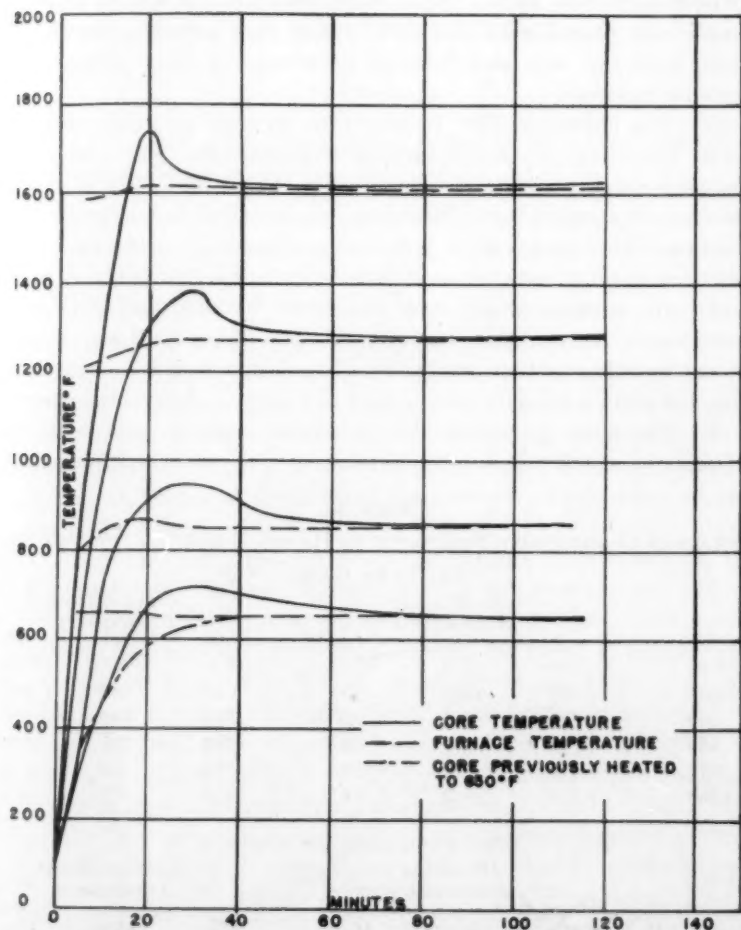


FIG. 12—COMPARISON OF FURNACE TEMPERATURE AND TEMPERATURE OF CORES AT THEIR CENTERS. NOTE EVIDENCE OF EXOTHERMIC REACTION IN CORES TESTED AT VARIOUS TEMPERATURES IN AIR, AND THAT NO EVIDENCE OF EXOTHERMIC REACTION IS INDICATED IN CORE PREVIOUSLY HEATED TO 650°F. THE CURVE FOR A CORE HEATED IN A NON-OXIDIZING ATMOSPHERE COINCIDES WITH THAT OF A CORE PREVIOUSLY HEATED TO 650°F.

were made from a core sand mixture similar to that described earlier, except for the addition of 1 per cent core oil. Cores were baked at 450°F. for 75 min. A $\frac{1}{8}$ -in. hole was drilled to the center of the core along its axis. A 24-gauge, iron-constantan, glass-insulated thermocouple, placed through a roof of a furnace, was inserted into the core, an asbestos sleeve pulled down over the thermocouple to cover the drilled hole, and the core placed in the furnace operating at the required temperature. A second thermocouple was placed near the core. Using two portable potentiometers, both the core and furnace temperatures were obtained at periodic intervals.

35. The curves in Fig. 12 illustrate the rate at which oil-sand cores, heated in air, reach furnace temperatures. The centers of the cores reach a maximum temperature that is 50 to 100°F. above the furnace temperature. This may be attributed to an exothermic reaction. This increase in core above furnace temperature was noted on heating both oil-sand cores with agent (sulfur and boric acid) and without agent, and with cores bonded with urea formaldehyde. By contrast, reheating a core which had once shown an exothermic reaction at 650°F., did not produce a second reaction, nor did an oil-sand core heated in a non-oxidizing atmosphere.

36. The cores producing the exothermic reaction took from 15-20 min. to reach furnace temperatures. The cores exhibiting no

Table 5

RETAINED COMPRESSIVE STRENGTH OF BAKED CORES, LB. PER SQ. IN.

OIL-SAND CORES						
Temp., °F.	Oxidizing Atmosphere			Non-oxidizing Atmosphere		
	30	60	120	30	60	120
	Min.	Min.	Min.	Min.	Min.	Min.
Room	940	940	940	940	940	940
650	225	160	90	595	590	525
850	90	30	25	405	275	240
1275	10	10	<5	70	50	45
1650	<5	<5	<5	<5	<5	<5

UREA FORMALDEHYDE CORES						
Temp., °F.	Oxidizing Atmosphere			Non-oxidizing Atmosphere		
	30	60	120	30	60	120
	Min.	Min.	Min.	Min.	Min.	Min.
Room	1550	1550	1550	1550	1550	1550
650	110	85	80	150	150	160
850	50	50	35	180	160	155
1275	10	5	<5	60	35	30

reaction took from 40-70 min. to reach furnace temperatures.

37. Cores were tested for collapsibility by heating for periods of 30, 60, and 120 min. at temperatures of 650, 850, 1275, and 1650°F. in both oxidizing and non-oxidizing atmospheres. To provide non-oxidizing atmospheres, the cores were placed in 2½-in. diameter pipe nipples, capped at both ends.

38. The same type of oil sand was tested as was used in the previous tests, and in addition, cores made with urea formaldehyde type of binder also were tested. The results are shown in Table 5.

CONCLUSIONS

39. From the data accumulated from the tests just described, the following conclusions may be drawn:

1. The heat content of aluminum alloys is about 70 per cent greater than magnesium alloys at comparable pouring temperatures of 1400°F. Bronze at 2100°F. contains 190 per cent and gray iron at 2500°F., contains 270 per cent more heat than magnesium alloys at 1400°F. These comparisons are on a volume basis.

2. The temperatures developed in the cores in the casting of magnesium are appreciably lower than those developed in the casting of aluminum, bronze, and gray iron. The length of time the core remains at an elevated temperature is also much shorter for magnesium.

3. When casting magnesium in ¼ and ½-in. sections, the major part of the core does not reach a temperature over 500°F.

4. Both oil and urea formaldehyde sand cores, irrespective of the presence of protective agents, produce an exothermic reaction on heating to 650°F. or higher in an oxidizing atmosphere. This reaction is not evident in non-oxidizing atmospheres.

5. An oxidizing atmosphere causes a much more rapid and complete collapse of both oil and urea formaldehyde core binders than does a non-oxidizing atmosphere.

6. Tests of core collapsibility involve consideration of temperature, time, and atmosphere to which the cores are exposed.

40. We conclude from these tests that the requirements for binders to be used for cores in magnesium alloy castings are unusual in that they should break down at lower temperatures and in shorter time intervals than core binders satisfactorily used in casting other common metals. The binders for cores used in the

production of iron and bronze castings break down because of the high temperatures they attain and the prolonged time at this temperature, thus permitting the easy removal of the cores from the casting. Because of the much lower temperatures attained by cores in the casting of magnesium alloys—seldom over 500°F.—and because of the short time they remain at that temperature, there is little breakdown of the core binder. The reducing atmosphere present in cores during casting magnesium alloys further retards that breakdown.

41. It is evident, then, that to facilitate removal of cores from magnesium alloy castings and to lower scrap losses, some binder must be found that will break down on short exposure to temperatures as low as 400°F. in a mold atmosphere. This means that baking temperatures for cores must also be very low. The core binder must either provide protection itself or be compatible with protective agents and with magnesium alloys.

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DISCUSSION

Presiding: DR. N. E. WOLDMAN, Eclipse Aviation, Pioneer Instrument Div., Bendix Aviation Corp., Bendix, N. J.

Co-Chairman: B. D. CLAFFEY, Gray Iron and Aluminum Div., General Malleable Corp., Waukesha, Wis.

CO-CHAIRMAN CLAFFEY: This paper, which was so ably presented by Mr. Peters, will be discussed and questions will be answered by M. V. Chamberlin of the Dow Chemical Company, the co-author.

O. J. MYERS¹: I would like to ask Mr. Chamberlin how he carried out these dilatometer tests under the oxidizing and reducing atmospheres.

MR. CHAMBERLIN: These tests were carried out in a muffle furnace having a temperature control of $\pm 5^\circ\text{F}$., and not in the familiar dilatometer so often used for this type of work.

To provide a non-oxidizing atmosphere the baked cores were placed in pipe nipples capped at each end. Following heating of the cores at elevated temperatures they were allowed to cool in the pipe fittings for 30 min. to prevent thermal shock, then transferred to a desiccator, cooled to room temperature, and broken in compression. The cores heated in air were removed from the muffle furnace to an insulated chamber to cool. After 30 min. they were transferred to a desiccator, cooled to room temperature, and broken in compression.

MR. MYERS: Did you use standard test specimens?

MR. CHAMBERLIN: Yes, 2-in. diameter by 2-in. high.

E. PRAGOFF, JR.²: This is an extremely valuable contribution to our knowledge of the properties required in core sands for light metal alloys. It is interesting to know that we need to go to such extremely low breakdown temperatures. We learned that through discussion with magnesium foundrymen over the past 2 or 3 years. One of the interesting facts that we discovered, through the use of the inhibiting agents, is that the agents themselves sometimes retard core breakdown, and they may do it not only by producing a reducing atmosphere, but they may do it by providing some core strength. I do not suppose you have investigated that yet in any measure, have you?

MR. CHAMBERLIN: No, we have not carried on any work on core sands without the addition of agents.

MR. PRAGOFF: We all need to dig into that a little bit, too. We have started off in that direction and have not progressed very far yet except to observe that, when we use rather large quantities of inhibitor, we may be doing some harm in knock-out.

MR. CHAMBERLIN: That may be true, but this is only the first stage of a continuing program. It is common today for most foundries to add agents to their core sands. Consequently, this program was started with that in mind.

MR. PRAGOFF: One other point is that we will be crowded down into a rather narrow temperature range of baking these core binders to achieve ideal results. Water boils at 212°F . and we cannot change that very

¹ Asst. Metallurgist, Wright Aeronautical Corp., Lockland, Ohio.

² Hercules Powder Co., Wilmington, Del.

much except by using a vacuum in the baking ovens. This means that, if we raise the temperature of a core to eliminate the water, we then have to accomplish the baking at some temperature, for example, 300 to 350°F., and that core later is going to break down rapidly below 450°F. This means that we will have to work in a very narrow temperature range and have much better circulation in core ovens.

Another factor I am wondering about is whether the authors have gone far enough in their work to conclude what would be a good retained strength range to insure fair core knock-out? In other words, would 100, 500 or 50 lb. per sq. in. retained strength be indicated?

MR. CHAMBERLIN: Retained strength must be tested under different temperatures and times at those temperatures. On the basis of our available knowledge, I do not think we can indicate what those limits might be.

MR. PRAGOFF: However, that could be achieved by correlating retained strength test data with ease of core removal and the knock-out operation in the foundry.

A. V. LORCH³: On your test, you mention that there is no difficulty for one inch below the surface of the core. Do you mean a 2-inch section of the core with the heat coming from both sides to a point one inch below the surface from each end?

MR. CHAMBERLIN: The cores were 2-in. in diameter by 2-in. high with a hole drilled through a distance of one-inch along the axis.

MR. LORCH: The curve showing the temperature versus the distance from the surface seemed to level off at one inch below the surface.

MR. CHAMBERLIN: Those particular curves were taken on a core 3-in. diameter by 8-in. long. We poured a cast cylinder of one-quarter, one-half and one inch sections of metal around these particular cores. The retained strength tests, however, were made on the standard 2-in. diameter core.

MR. LORCH: I am referring to the curve showing temperature versus depth from the surface. Your curve for the temperature obtained seemed to level off at a minimum of about 400°F. for one inch from the surface. If you went further from the surface, would the curve continue to level off as nicely as it did or would it start to drop sharply? I notice in the early part of the temperature curve that you had a place where the curve leveled off on the way up. I wanted an explanation of that, too.

MR. CHAMBERLIN: In the tests to which you are referring, the test piece was a 3-in. diameter by 8-in. long core which contained four thermocouples. One thermocouple was placed an eighth of an inch, another one-quarter, another one half, and the fourth one inch from the surface. We had a one-eighth inch pipe running lengthwise of the core, and the fourth thermocouple was very close to the pipe, indicating very closely what the temperature was at the center of the core.

As an explanation of why these curves leveled off, and in some cases even began to rise afterwards, it is to be considered that the tempera-

³ Eclipse Aviation Div., Bendix Aviation Corp., Bendix, N. J.

ture at any point in the core is determined by two things: (1) the heat input to that particular point and (2) the rate at which heat is extracted from that point. During the initial stages of the solidification, the casting itself is at very high temperature and the core temperature is quite low, with the result that we are heating the core at the surface rapidly to what we might call maximum temperature. At the same time, a definite point near the surface of the core is passing heat off to the interior. When we get to a certain range, which would be near the heat of fusion of the metal, the casting remains at one temperature and gives off heat to the core at a constant rate instead of a steadily decreasing rate. However, the interior of the core is still abstracting heat at a comparatively high rate, causing a hump in the curve. After solidification is complete the core temperature may still continue to rise to a maximum, then drop off as the casting becomes cooler.

L. W. BALL⁴: I would like to ask whether hollow cores have been experimented with to increase collapsibility? Suppose, in the 3-in. diameter core, you had a 1-in. diameter hole down the middle. Would the core collapse so much more easily that you would avoid knock-out cracks?

MR. CHAMBERLIN: These cores were not hollowed out. However, they had the one-eighth inch pipe running through the center by which gases could be vented very rapidly. The pipe itself had vent holes at regular intervals.

MR. BALL: You could reduce the thermal capacity of the core by making it hollow, and, you could give it a place into which it could collapse. Have those theoretical ideas ever been applied in practice?

MR. CHAMBERLIN: I believe that the heat capacity of the core would have little effect on the collapsibility. Collapsibility will be due to the characteristic of the binder.

MR. BALL: The temperature rise will increase if the thermal capacity of the core is decreased.

MR. CHAMBERLIN: Providing the heat conductivity remains the same. We have some reason to believe that conductivity may play a more important part than thermal capacity.

MR. BALL: Have any of the practical foundrymen present tried hollow cores to increase collapsibility?

MR. PETERS: Shell cores have been used in production with a good degree of success in many cases. We did not use shell cores in these experiments.

MR. BALL: Another point is that you are reporting the manifestation of high core strength in the form of cracks. In aluminum, we can pick out too high core strength by shrinkage segregation. Here is an x-ray picture (Fig. 13) in which, in the 195 alloy, we see a line of eutectic where the contraction of the metal had been resisted by a core that had failed to collapse. The eutectic had filled up the incipient crack. Do you get a eutectic segregation in magnesium as an indication of too great core strength?

⁴ Research Physicist, Triplett & Barton, Inc., Burbank, Calif.

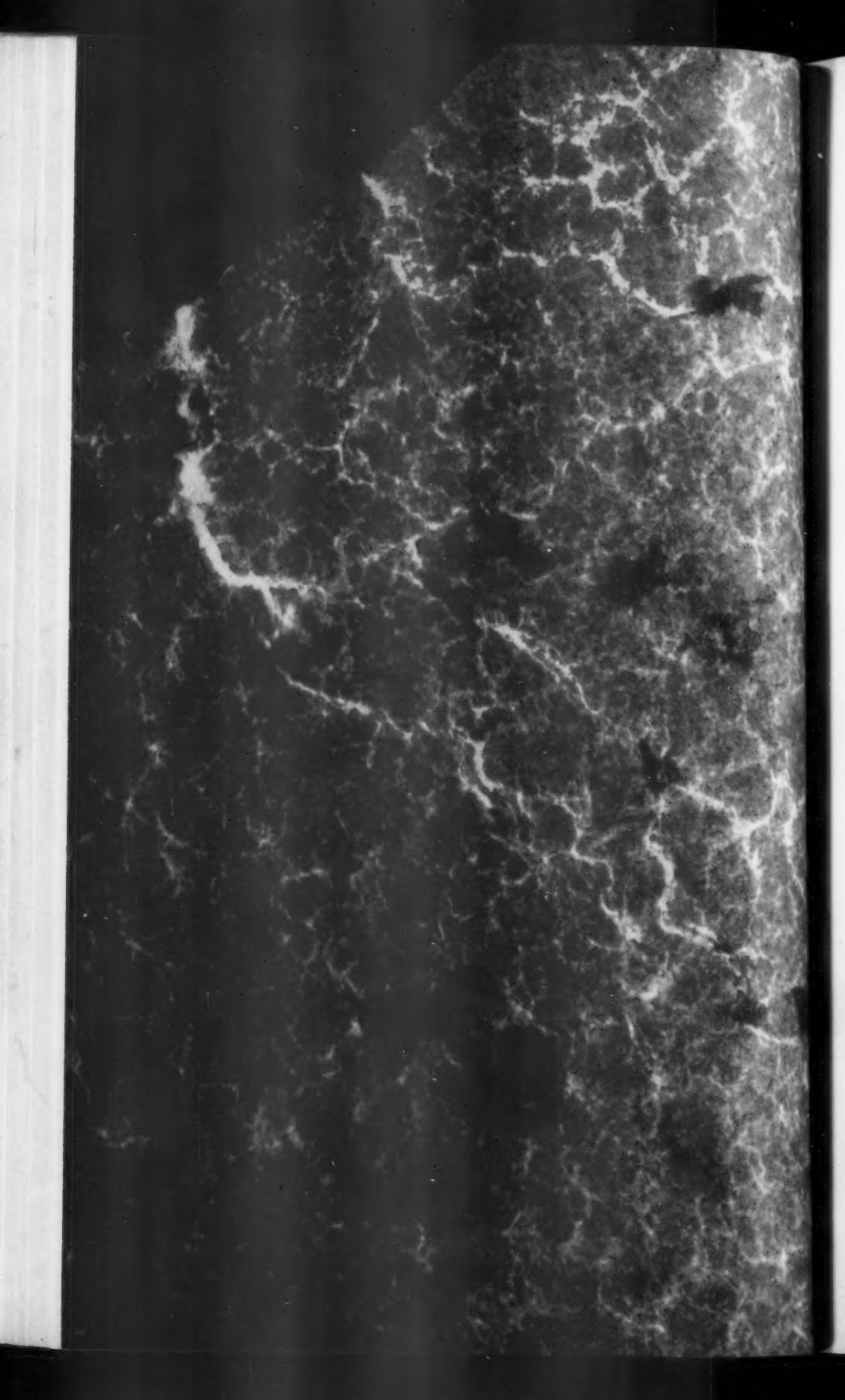


FIG. 13—AT LEFT—MICRORADIOGRAPH OF A SECTION OF 195 COPPER-ALUMINUM ALLOY 0.016 IN. THICK, SHOWING SHRINKAGE SEGREGATION. IN THIS PICTURE THE COPPER-RICH EUTECTIC IS RELATIVELY OPAQUE TO X-RAYS AND APPEARS WHITE. THE JAGGED BLACK AREAS ARE MICROSHRINKAGE CAVITIES. MAGNIFICATION X30.

MR. PETERS: I would certainly expect that situation to exist, although our primary concern, to date, has been with the core knock-out rather than with the other problems relating to the quality of the casting. They do not seem to be as severe in magnesium as they are with some other metals.

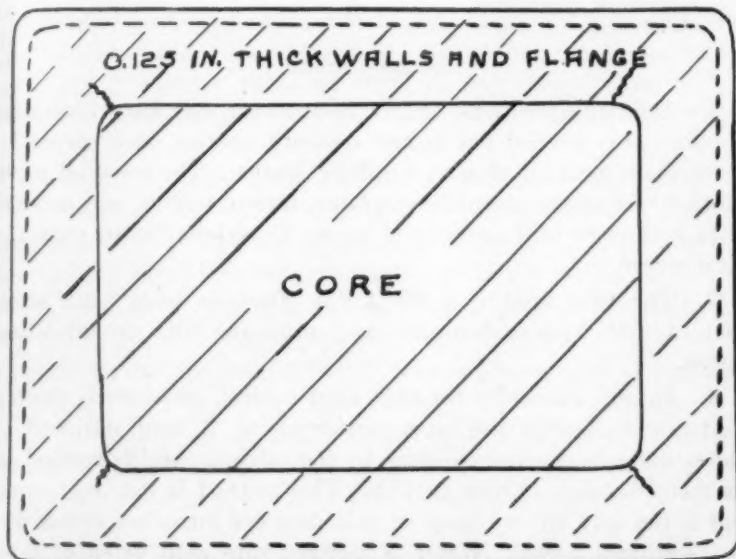


FIG. 14—THE LOCATION OF THE EUTECTIC-FILLED INCIPIENT CRACK.

MR. BALL: This problem of resistance to the contraction of the cooling metal is not limited to cores. We do get trouble with the mold sand itself. For example, in a box type casting, we may have a rectangular area, say 4 x 5-in., in which the core sand protrudes 2-in. into the casting. Failure of the mold sand to collapse can produce shrinkage segregation (Fig. 14). Should the same ideas about using a low temperature breakdown for the core be applied to molding sand?

MR. CHAMBERLIN: Initially, the dry strength of the molding sand is very much lower than it is with the core sand, and we have very little trouble due to the molding sand failing to allow the necessary shrinkage of the casting.

Magnesium Foundry Sand Control

BY F. S. BREWSTER*, BAY CITY, MICH.

Abstract

Methods of sand handling and control measures in molding operations for magnesium castings are presented in this paper. The system of tests and equipment used in the author's foundry are described in detail. The handling and testing routine is shown as a practical adaptation to the molding requirements in magnesium casting operations.

MOLDING SAND

1. Molding operations, as practiced at the Bay City Dowmetal Foundry, are carried out in two separate systems, each served by a complete mechanical sand handling system. The essential parts of each system are magnetic separator, screen, muller, and aerator, with a hammer mill and second screen to reclaim lumps from the first screen.

2. The base sand is a 90 A.F.A. fineness local bank sand, bonded with western bentonite and protected with an inhibiting agent.

3. In any scheme of foundry sand control, moisture is the big factor and deserves the most consideration. A man stationed at the mullers determines moisture by the calcium carbide method on as many batches as time permits. This method is not only rapid but is the only one we know of that does not introduce errors due to volatilized agents. Water is metered into each batch of sand according to the results obtained on the previous batch. For a one-ton batch, the water added will vary from 4 to 5 gal. for the general run of returned shake-out sand. Moisture is held in the range of 3.9 per cent to 4.3 per cent at the muller. About 0.2 per cent is lost by the time the molder gets the sand.

4. On each shift, four samples from the molder's hoppers on each system are taken to the laboratory where they are tested for moisture, green permeability, and green compression. Two tests are made on each sample, and a third test is made if the first two are not in good agreement. Due to the slow rate at which bond

* Metallurgist, Dow Chemical Co.

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and agent burn out in magnesium sands, more frequent samples are not necessary. Once a week the samples are also run for dry permeability, dry compression, clay wash, and grain fineness. Twice a week composite samples from each system are sent to the chemical laboratory for agent analysis, which consists of a total water soluble figure and elemental or free sulphur content.

5. Green compression is controlled at 7.5 to 9.0 lb. per sq. in. by varying additions of bentonite. Green permeability usually varies from 70 to 90 and if it is felt necessary to change this range, either a change of base sand or an adjustment of the dust collecting system can be made. The amount of protective agent is controlled by carrying about 3 per cent total water soluble matter. Additions of inhibiting agent are made on each shift to maintain this figure.

6. Each shift weighs out the total bentonite and sand agent addition, and distributes it throughout the shift, adding a little to each batch. This may sound haphazard but with a little practice the additions and batches come out surprisingly even.

7. Our system, handling 175 to 200 tons of sand per shift, will use 150 lb. of bentonite and 500 lb. inhibiting agent. This system handles heavy work and represents about the maximum of required additions.

8. No facing is used and all jobs use the same sand. In addition to the tests on the mixed sand, the base sand is tested as received for grain fineness, base permeability, and clay.

CORE SAND

9. Core sand is prepared in double-blade, intensive mixers. Sand and dry ingredients are weighed and liquids are metered. Two main types of sand are used, (1) a jacket sand of 1.0 lb. per sq. in. green compression and 180 lb. per sq. in. baked tensile strength, (2) and a hub sand of 1.5 lb. per sq. in. green compression and 150 lb. per sq. in. baked tensile strength. There are several other mixes of which small amounts are used, such as blast sand, zircon, chill shot, blow sand, and patching sand.

10. On each shift, samples of each type of sand from each of two core rooms are collected and tested for moisture, green permeability, green compression, baked tensile strength, and hardness. A dry permeability test is run once a week. The base sand is a local dried bank sand of 60 to 70 A.F.A. fineness.

11. Moisture is tested by the calcium carbide method. It is held at 6 per cent for the jacket sand, 4 per cent for the hub sand, and 2 per cent for the blow sand. The green strength is critical on the hub sand and adjustments of bentonite and corn flour are made to hold it steady. The baked strength on all mixes is controlled from day to day by varying the amount of core oil. From 4 to 5 qt. of oil are used for 900 lb. of sand and changes are made by $\frac{1}{4}$ of a quart steps. We find that there is enough variation in any sand to warrant this practice. The demands of the core room for cores hard enough to handle, and of the knock-out crew for cores soft enough to get out, do not leave much room for variation of strength. We try to hold a 20 lb. range on all sands, although this seems, at times, to be practically impossible.

12. All tests are carried out with standard A.F.A. methods. It is important here to note that if core sand tests are used to control the mix, samples must be baked in a standard laboratory oven, to eliminate the variables of shop baking.

(For discussion, see page 191)

Molding and Core Sand Characteristics in a Light Metal Foundry

By A. V. LORCH*, BENDIX, NEW JERSEY

1. The foundry sands used in our magnesium and aluminum foundries are prepared to conform to the requirements necessary for the successful sand molding of light metal castings. We have recognized the fact that light metal castings, in general, have a lower specific heat and density, and greater shrinkage, than heavy metal castings. Our molding sand combines the highest permeability available with the low green strength required. Our core sand has the green strength necessary for forming intricate cores, high permeability to allow ample venting of gases, and dry strength which is great enough to minimize breakage in handling yet low enough so that the cores yield as the metal shrinks while solidifying.

2. Green molding sand is made available for the molds either in batch piles or in hoppers fed from a conveyor belt. The sand is conditioned for use in the batch system by means of aerators. Sand is conditioned for use in the hoppers by means of large mullers, which are more efficient and give more uniformity and higher physical properties than are obtainable with a batch pile conditioned by aerating.

3. Because of the lack of mulling facilities, a natural bank sand of the Albany type is used in batch piles. This sand has an A.F.A. grain fineness number of about 120 and a clay content of about 10 per cent, and gives best all around service in our batch system. However, in using the conveyor system, it was found that natural sands were unsuitable, as clay balls were formed as the sand passed along the conveyor belt. Therefore, a synthetic sand has been utilized, which yields superior results both as to physical properties and texture. The synthetic sand consists of a sharp-grained silica sand having an A.F.A. fineness number of 80 to 100, with a 4 per cent clay addition of the bentonite type.

4. Natural sands require between 6 and 8 per cent moisture to obtain the proper green strength, while synthetic sands require from 3 to 4 per cent moisture to attain properties, which in the

*Eclipse Foundry Division, Bendix Aviation Corporation.

NOTE: This paper was presented at a session of Sand Shop Course at the 47th Annual Meeting and Second War Production Foundry Congress, St. Louis, Mo., April 28, 1943.

opinion of the author, are superior to the natural sand. Higher permeability and higher strength are usually obtainable with synthetic sand.

5. It is necessary to add inhibiting agents to molding sand used for magnesium alloy castings to prevent oxidation of the alloy as it runs into the mold. An approximate analysis is obtained by determining the water soluble content in the sand, which is an indication of the total of inhibiting agents present. Chemical analysis of the inhibitors will be put into practice in the near future.

6. The trend in core sands has been towards silica sand mixtures, with the exclusion of river bed sands, which have been found to be non-uniform and to have an iron content of 1 to 2 per cent. It has been found that silica sands are more uniform than river bed sands over a long period of time, and it is possible to make cores showing consistent results. In addition, improved physical properties result in cores made from the silica sand mixtures. The general types of core sands used are:

1. *Sand for use in blower machines.* Round-grained silica sand, A.F.A. fineness no. 80, is used in the core blowing machines. The sand is mixed in a ratio of 48 qt. of sand to 1 qt. of oil. It has a low green strength and a good dry tensile strength.

2. *Core sand for hand ramming.* This sand consists of a mixture of equal parts of A.F.A. fineness no. 80 round-grained silica sand and A.F.A. fineness no. 160 sharp-grained silica sand. Core oil is added to this mixture to obtain dry strength, and a dry cereal binder is added to increase the green strength. The physical properties obtained vary with the proportion of sand to oil and binder used. All cores are baked in continuous or in batch type ovens for a period of 3 hours at 450°F. If the cores are to be used in magnesium castings they are sprayed with a saturated solution of ammonium boro fluoride and ammonium acid fluoride and dried for 10 to 15 min. at 400°F.

(For discussion, see page 191)

Sand Practice in a Canadian Light Alloy Foundry

By A. E. CARTWRIGHT*, MONTREAL, CANADA

Abstract

Exclusive use of facing sand for all work in the casting of light alloys, as a means of reducing losses on castings subject to rigorous radiographic inspection, is the author's objective. Quantities of various materials used are shown in Tables. A routine of checks and tests, as a means of constant material control, is given.

TYPE OF PRODUCTION

1. Aluminum and magnesium alloy castings, the great majority being for aircraft structural parts and subject to rigorous x-ray control and inspection, are produced in the foundry with which the author is connected.
2. The majority of parts are produced by machine molding, using composition match plates and snap flasks.

SYNTHETIC SAND USED EXCLUSIVELY

3. Synthetic sand, using white silica sand and bentonite, is standard practice for both aluminum and magnesium alloys, and simplification, by keeping sand varieties to a minimum for both cores and molds, is a cardinal principle.
4. Two grades of silica sand, of the grain analysis shown in Table 1, are mixed to provide the characteristics required.
5. The heap sand is originally composed of 50 per cent of each

Table 1

SIEVE ANALYSIS OF SANDS USED

Retained on Sieve	Coarse Silica per cent	Fine Silica per cent
No. 40	4.60	0.0
No. 50	17.40	0.0
No. 70	29.40	4.08
No. 100	33.10	18.36
No. 140	11.40	22.96
No. 200	1.68	19.10
No. 270	0.26	22.10
Pan	0.0	13.10

* Chief Metallurgist, The Robert Mitchell Co., Ltd.

NOTE: This paper was presented at a session of Sand Shop Course at the 47th Annual Meeting and Second War Production Foundry Congress, St. Louis, Mo., April 28, 1943.

grade of sand, and contains 5 per cent bentonite worked at 4 to 5 per cent moisture. Sand conditioning is accomplished by hand methods, assisted by aerators, with constant checking for moisture throughout the day and for permeability and shear strength of the heaps, in rotation.

USE OF FACING SAND FAVORED

6. The exclusive use of facing sand for all work is our aim, and the present extent of its use is limited only by mulling capacity, which is difficult to increase under present conditions.

7. Most of the snap flask work utilizes facing sand prepared, using the heap sand as a base, by the addition of new silica, (1) for maintaining the heap, and (2) for governing surface fineness. For castings requiring particularly smooth surface, the entire addition of new sand may be of the fine grade.

8. Constant testing of facing sands is performed in the mixing department and moisture is maintained at $2\frac{1}{2}$ to 3 per cent.

9. The use of facing sand, thoroughly controlled, especially as to moisture content, has proved one of the most effective means of reducing and preventing losses due to porosity and blow holes at the stage of radiographic inspection. Backing sand qualities are, in this practice, less significant and a wider variation in properties is permissible. Use of controlled facing sand is particularly advisable in magnesium practice as a ready means of controlling the quantity of inhibitors used and of reducing the total quantity of sulphur required for adequate protection against burning of the magnesium alloys. Inhibitors in backing sand are adequately maintained by the residue of them left by the facing sand dilution. Facing sand for magnesium alloys, for most purposes, contains 5 per cent sulphur and $\frac{1}{2}$ per cent boric acid.

10. In Table 2, an average range of qualities of molding sand is shown.

Table 2
MOLDING SAND PROPERTIES

	<i>Moisture per cent</i>	<i>Permea- bility No.</i>	<i>Shear Strength lbs.</i>
Aluminum Heap	4.0-5.0	40-60	3.0-4.0
Aluminum Facing	2.5-3.0	30-50	3.0-3.5
Magnesium Heap	4.0-5.0	80-90	3.5-3.0
Magnesium Facing	2.5-3.0	50-80	3.0-3.5

CORE SAND MIXTURES

11. As stated previously, the same sand base is used for cores as for molds. Fine and coarse silica sands are mixed; not usually finer than 50 per cent each, frequently 100 per cent coarse, and occasionally, for very open large cores, some 20 mesh sand may be included. Binders used are shown in Table 3.

Table 3

CORE BINDERS USED

Bentonite, per cent	1.50-3.00
Cereal Binder, per cent	1.00-3.00
Core Oil, proportion	25 to 50-1
Water, per cent	6.00-9.00

Proportions depend on types of cores, of which there is a great variety.

12. When core drying equipment is used the quantities of bentonite and cereal binders necessary to provide green strength will be reduced below the minimums shown in Table 3, as more equipment of this type becomes available.

SOME ADVANTAGES OF PRESENT SAND PRACTICE

13. Our practice has resulted in several advantages, the chief of which are:

1. Ease of control of sand qualities and of reproducibility of these qualities.
2. Greater permeability properties for equal surface quality than with natural-bonded sands.
3. Low sensitivity to variation in the ramming practice of different operators and less tendency to defects associated with faulty ramming of molds.
4. Elimination of the use of bands and weights on snap flask work, saving much space and labor.
5. Durability and life of the synthetic sand is much in advance of the natural sands heretofore used.
6. Elimination of hand venting by high permeability.
7. Ideal strength properties allow of drawing and lifting deep and large molds without reinforcements by bars, gagers, nails, etc., thereby saving much molding time.

(For discussion, see page 191)

Magnesium Foundry Sand Practices

By M. E. GANTZ*, CLEVELAND, OHIO

1. In a discussion of foundry sand practices, as carried out in the foundries of The American Magnesium Corporation, we should first consider those properties, peculiar to magnesium, which necessitate the special precautions and addition agents employed in making magnesium molding sand mixes.

2. The two properties of magnesium base alloys which dictate special foundry sand practices are the low specific gravity of the alloys, and their tendency to react with mold gases. Let us discuss each of these properties and the provisions made to offset its effect.

Specific Gravity

3. The low specific gravity of magnesium base alloys results in an increased sensitivity toward mold gas pressure. Relatively low gas pressures are sufficient to cause blows or misruns. To compensate for this, magnesium molding sands must have good permeability to exhaust mold gases. Also, the gas-forming ingredients in the sand mix should be kept at a minimum.

Reaction With Mold Gases

4. The second distinctive property of magnesium alloys is their tendency to react with mold gases, particularly steam. This will result in partial or complete casting destruction unless a protective agent or inhibitor is provided to prevent reaction of the metal with these gases. There are two methods by which these inhibitors may function:

1. They may boil or decompose between 150 and 500°C., resulting in a gas which will not react with magnesium, but which will form a protective atmosphere in the mold by diluting the active gases present.

2. They may provide the magnesium with a protective skin, thus preventing further reaction.

5. Each of these types of protective agents has its advantages, and the use of one or the other depends on the individual foundry.

* American Magnesium Corporation.

NOTE: This paper was presented at a session of Sand Shop Course at the 47th Annual Meeting and Second War Production Foundry Congress, St. Louis, Mo., April 28, 1943.

6. Turning now to actual molding sand mixes, a typical mix used is shown in Table 1.

Table 1

<i>Per Cent</i>	<i>Material</i>
89.0	Geauga blend sand
3.0	Western bentonite
2.0	Boric acid
1.5	Sulphur
2.0	Diethylene glycol
2.5	Water

7. In the mix shown in Table 1, the boric acid, sulphur, and diethylene glycol are the protective agents. They are of the type which forms a protective atmosphere in the mold. In addition to the protective effect of each of these agents individually, the boric acid is thought to react with the diethylene glycol, forming an ethylene borate which has good high temperature protective properties.

8. The sand used is a product of the Cleveland district. It is washed and dried, subangular in character, and has an A.F.A. grain fineness of around 60. A typical sieve analysis of this sand is shown in Table 2.

Table 2**SIEVE TEST**

<i>Mesh No.</i>	<i>Per Cent Retained</i>
12
20	0.10
30	0.90
40	3.60
50	20.40
70	37.60
100	24.40
140	11.10
200	1.50
270	0.20
Fan	0.20

9. The molding sand heap is controlled by checking certain physical properties daily. The properties tested and their average values are shown in Table 3.

Table 3
SAND PROPERTIES

<i>Properties</i>	<i>Av. Values</i>
A.F.A. Permeability	140
Green Compression Strength, psi.	6.25
Green Shear Strength, psi.	2.00
Flowability, per cent	76
Mold Hardness*	77
Deformation at rupture, in. per in.	0.032

Moisture

10. In addition to the foregoing tests, a routine moisture check is made daily. The moisture is held between 2.3 and 2.7 per cent. This control is very important, as excess moisture results in steam blows, reaction, and even in occasional mold explosions.

11. Unlike molding sands in other foundries, we find that our sand heap gets stronger with use. Therefore, it is occasionally necessary to make new sand additions which contain a reduced amount of bentonite. All new sand added to the heap is mixed very thoroughly before being dumped into the system.

Sand Handling Equipment

12. In concluding, it might be well to mention something about our sand handling equipment. We have closed circuit sand systems in all of our foundries, the sand being remulled after each use. The mulling equipment consists of two types of muller-type mixers. None of the sand is thrown away, but new sand additions are necessary to replenish sand lost from the system.

* Mold hardness taken at bottom of standard rammed specimens.

(For discussion, see page 191)

DISCUSSION

Presiding: F. S. BREWSTER, Dow Chemical Co., Midland, Mich.

O. JAY MYERS¹: Mr. Chairman, on Mr. Cartwright's paper, I would like to ask why he takes the shear strength of the sands instead of the green compression strength, or some other physical property?

MR. CARTWRIGHT: Because we have only a shear test machine available.

MR. MYERS: Did you use the standard C. P. Universal Testing Machine?

MR. CARTWRIGHT: I do not recall, but it is an old one, just a half-cylinder shear.

MR. MYERS: Did you take the flowability or the mold hardness of your sand at any time?

MR. CARTWRIGHT: We test the hardness of molds when we are checking on the technique used for new jobs, but we do not test flowability.

MR. MYERS: When you run tests on the core sand mixtures, do you bake the specimens and find out some of their physical properties, such as tensile strength? Do you have any information on these physical properties?

MR. CARTWRIGHT: No, we have not made any actual physical tests on the core sands. We insist upon getting a collapsible core for aluminum sands, and we watch our core room practice to be sure of that.

MR. MYERS: Do you find that bentonite gives you a retained strength and retards collapsibility?

MR. CARTWRIGHT: Yes, to a certain extent, particularly if you use much water. However, if we do not have core driers for all types of cores (in some cases we do not have them) and we need a certain amount of green strength, the best way to get it is with the use of some bentonite.

PAUL F. HABER²: Mr. Brewster, I would like to ask a question on the test you said you ran once a week, or every so often, on X-ray defraction on your sands. Can you elaborate upon that a little bit?

CHAIRMAN BREWSTER: I do not know too much about that, but I see Mr. Brooks in the audience and he might have something to say about this X-ray defraction pattern on water soluble.

M. E. BROOKS³: The only thing it does is to break down the water soluble and indicate the actual compounds which are present. While that is interesting information, we do not feel that it is really essential.

MR. HABER: I have another question for Mr. Brewster. Although I am in an aluminum foundry, I think the matter pertains to both aluminum and magnesium. How do you test your raw materials, such as oils and binders and materials of similar nature? At present, in our foundry, we run standard chemical tests; however, we are seriously considering the advisability of making standard cores, in a standard laboratory

¹ Wright Aeronautical Corp., Lockland, Ohio.

² Ford Motor Co., Dearborn, Mich.

³ Dow Chemical Co., Bay City, Mich.

oven, and not worrying so much about the chemical composition of the materials, but simply trying to obtain definite physical properties. I wonder if you, or perhaps some of the other members here, have any ideas along that line?

CHAIRMAN BREWSTER: My personal inclination is to determine the actual performance of the binder in the sand that is going to be used. I was never greatly interested in the chemical composition of core oils and binders, as long as they do what I want them to do. I think you are perfectly right to set up a standard test batch and test your binders, varying only one thing at a time.

MR. MYERS: In our laboratory, we have started to do some serious testing of the vendors' products and, in that respect, we set up certain standard qualifications for them. We use a definite amount of solid binder or oil in a standard mix. That is, we add the binder in question to a controlled sand mixture. A specific percentage of water is maintained. The sand mixture is then kept in moisture-proof jars until used. Several American Foundrymen's Association standard plates are made up, consisting of 4 tensile specimens, 3 transverse specimens and one permeability specimen. These specimens are baked in a controlled oven for different lengths of time and at different temperatures. The first test is to obtain that temperature which will give the highest tensile strength. In the case of cereal binders, it is usually between 350 and 400°F.

After that test has been completed, we determine the optimum physical properties and we begin a "time" test. This test consists of baking the same types of cores at the optimum temperature (from the first test) for different periods of time, from 2 to 6 hours at 1-hour intervals. By that method we determine the optimum baking time.

All of these cores are made from one batch of sand, mixed in a laboratory muller-type mixer.

After we have the temperature and the time test completed, we feel that we have the optimum baking conditions for the binder in question. We then make dilatometer tests (hot strength and dilation). This test is made under our own standard procedure at 1200°F. We determine whether the binder is collapsible, and its degree of collapsibility with respect to other binders previously tested.

Chemical Analysis of Sands for Magnesium Castings

By EUGENE M. CRAMER,* Pullman, Wash.

Abstract

When inhibitors are present in improper quantities in magnesium foundry sands, they have a detrimental effect not only on the metal itself but also jeopardize the production of quality castings. Therefore, it is essential that the quantity of inhibitors present be controlled. The author in the following paper suggests chemical methods to accomplish this control.

INHIBITORS are a necessary part of magnesium foundry sand in modern practice. Insufficient quantities result in a reaction between the molten metal and both the moisture in the sand and the sand itself. The effects appear on the thickest sections, and at points where the greatest amount of metal flows through the mold.

Their function is accomplished¹ by (1) forming an enveloping protective atmosphere, (2) forming a protective skin on the flowing metal by reaction, (3) isolating the sand grains with fused products, and (4) by locally lowering temperatures by their heats of fusion or vaporization.

Sulphur is the most important inhibitor, and is probably of the first type, that is, a protective atmosphere is formed. Ammonium fluosilicate is of the second type, giving a surface on the casting resistant to oxidation. Boric acid acts as types 2 and 3, forming a skin and isolating the sand grains.²

Two main types of sand are in common use. Type A contains 2 to 10 per cent sulphur, 0.5 to 1 per cent boric acid, 2 to 4 per cent bentonite, about 1 per cent diethylene glycol, about 4 per cent water, and the balance silica sand. Type B contains 2 to 10 per cent sulphur, 0.5 to 1 per cent boric acid, 2 to 4 per cent bentonite, 2 to 4 per cent ammonium fluosilicate, about 5 per cent water, and the balance silica sand.

The degree of control necessary is obtained by adding the requisite amounts of bonding and inhibiting materials to silica sand, and by frequent routine analyses. The need for a rapid and reasonably accurate method for handling these analyses was pointed out by H. P. Nielsen, Metallurgist for Kinney Aluminum Co., Los Angeles, and his counsel and advice has been of great value in selecting the procedures.

These routine methods have been selected carefully and tried out in order to eliminate time consuming separations and filtrations, and to allow over-lapping

*Junior Research Metallurgist, Washington State College Mining Experiment Station.

of the determinations by using separate samples for each substance where convenient.

Analysis of Sand A

WATER

Dry a sample of the sand in an oven at 90-95° C. (194-203°F.) for an hour and calculate per cent of water direct. For a 10 gram sample: (loss of weight) $\times 10 =$ per cent water.

BORIC ACID³

Reagents: 0.5N. NaOH. Prepare by dissolving 22 gm. of NaOH in 300 ml (milli-liters) distilled water, add 20 ml of 0.5 normal BaCl₂, settle, and decant into 1,000 ml volumetric flask. Fill to mark with boiled, distilled water, settle again and siphon off the clear liquid into a bottle protected by a soda-lime tube. Standardize against a standard acid, using phenolphthalein as indicator.

Phenolphthalein Indicator: Dissolve 1 gram phenolphthalein in 50 ml ethyl alcohol, and add 50 ml water.

Procedure: Place 10 gram sample in 250 ml Erlenmeyer and treat with 50 ml water until acid is dissolved. Add 20 ml glycerine; 4 drops indicator, and titrate to a permanent end point with NaOH. Add 10 ml glycerine again, and if the end point fades, continue the titration.

Reaction: Boric acid reacts as a monobasic acid, and 1 mol H₃BO₃ is equivalent to 1 mol NaOH.

Calculation: 1 ml 0.5N. NaOH = 0.0309 gms. H₃BO₃.

DIETHYLENE GLYCOL^{4,5,6,7,8}

Reagents: Acetic anhydride-pyridine solution:

Prepare by mixing 88 ml color-

less pyridine with 12 ml acetic anhydride. This should be prepared fresh for each group of determinations.

0.5N. NaOH.

Phenolphthalein.

Procedure: Place a 10 gram sample, which has been thoroughly dried, in a 250 ml Erlenmeyer flask. Pipette 20 ml of acetic anhydride-pyridine solution into the flask, and prepare a blank of 20 ml in another flask. Attach reflux condensers and boil gently for a few minutes on a hotplate, then wash out the condenser and sides of the flask with 50 ml water. Cool the flasks, and titrate cold with NaOH, using phenolphthalein as an indicator. Add 20 ml glycerine and continue titration as for boric acid.

Reaction: The acetic anhydride reacts with the glycol by acetylation of hydroxyl groups, and the remaining anhydride is decomposed by the addition of water to acetic acid. The acetic acid is titrated with NaOH.

Calculation: (Blank ml — ml used) + (ml from boric acid determination) = ml equivalent to acetic anhydride reacted.

1 ml 0.5N. NaOH = 0.0265 grams diethylene glycol.

SULPHUR^{9,10}

Reagents: Sodium sulfite (Na₂SO₃)
40% solution, by vol., of formaldehyde (HCHO)

20% solution of acetic acid (HC₂H₃O₂)

0.1N. Iodine solution

Prepare by dissolving 12.7 grams I_2 in 100 ml water containing 21.0 grams KI. Stir until dissolved. Transfer to 100 ml volumetric flask and dilute to mark. Store in a glass stoppered bottle in a dark place. Standardize against As_2O_3 . Weigh 0.1000 grams As_2O_3 into small beaker, and dissolve in 10 ml 5% NaOH by warming gently. Acidify with HCl, add an excess of $NaHCO_3$, and titrate with iodine solution, using starch indicator.

Starch Indicator. Prepare by grinding 1 gram of soluble starch into a thin paste in an agate mortar with a small amount of water. Wash into 150 ml boiling water, boil for 4 min. Filter if necessary. Fresh solution each day.

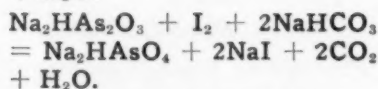
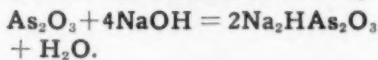
Procedure: Place 10 gram sample in a Kjeldahl flask, or a round-bottom flask of about 300 ml capacity with reflux condenser (a motor stirrer with a long glass paddle is necessary to prevent bumping). Add 75 ml water, 4 grams Na_2SO_3 and boil for 45 minutes to 1 hour until the sulphur is dissolved as a thiosulfate.

Cool, and transfer to a 250 ml volumetric flask, add 40 ml of formaldehyde solution, 10 ml of acetic acid solution, and fill to mark with repeated washings of the flask and sand. Titrate immediately.

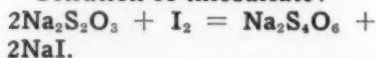
Pipette 25 ml into a 250 ml Erlenmeyer flask and titrate rapidly with I_2 . When titration is nearly completed (brown color fades slowly) add 5 ml starch solution and titrate to blue color. The end point

fades due to decomposition of the formalin-sulfite compound.

Reaction: Standardization of I_2 :



Titration of thiosulfate:



Calculation: 0.1000 gram As_2O_3 = 0.2565 grams I_2 .

1 ml 0.1N. I_2 = 0.0032 grams S.

SULPHITE AND SULPHATE IN USED SAND

Reagents: *Lorol amine hydrochloride DP243 (Du Pont)*

Bromine water

10% solution of $BaCl_2$

Procedure: To a 10 gram sample, add 50 ml water and heat to dissolve sulphates, add 2 drops DP243 to precipitate bentonite, and mix thoroughly. Filter by suction, wash with water, and discard residue. Acidify the filtrate with HCl, add 5 ml of bromine water and boil until Br_2 is expelled. Add 20 ml of 10% $BaCl_2$ solution slowly from a burette, and digest for 1 hour on a water bath. Filter through a weighed Gooch crucible (or No. 42 filter paper) wash with hot water, dry, and ignite gently to constant weight. Weigh as $BaSO_4$.

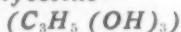
Calculation: $BaSO_4 \times 0.1373 = S$.
 $BaSO_4 \times 0.4115 = SO_4$

Analysis of Sand B

The determination of moisture and sulphur is by the same methods as with sand type A.

BORIC ACID¹³**Reagents:** 0.5N. NaOH

Glycerine—

BaCl₂

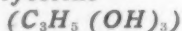
Phenolphthalein

Procedure: Place 10 gram sample in a 250 ml Ehrlenmeyer flask, add 20 ml water, 1 gram of BaCl₂ • 2H₂O to precipitate the fluosilicate, and shake until dissolved. Wash down the sides of the flask and leave overnight.

Add phenolphthalein and titrate carefully with NaOH to the first tinge of pink (fades), being careful not to overstep. Note the burette reading now. Add 20 ml of glycerine and titrate the boric acid with NaOH to a permanent end point.

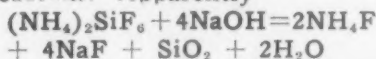
AMMONIUM FLUOSILICATE^{13 14}**Reagents:** 0.5N. NaOH

Glycerine—



Phenolphthalein

Procedure: Place 10 gram sample in a 250 ml Ehrlenmeyer flask, add 50 ml water, and heat nearly to a boil. Add phenolphthalein and titrate to pink while hot. Cool the solution, add 20 ml of glycerine and titrate to a permanent pink. Both H₃BO₃ and (NH₄)₂SiF₆ are neutralized.

Reaction: Apparently

Calculation: (ml used) — (ml used for boric acid) = ml equivalent to (NH₄)₂SiF₆.

1 ml 0.5N. NaOH = 0.0223 grams (NH₄)₂SiF₆.

In the titration of boric acid in the presence of precipitated barium fluosilicate, a part of the acid is neutralized in the first addition of sodium hydroxide, and as a result, the fluosilicate figure will consistently be high and the boric acid low by about 5 per cent. It is believed, however, that the methods are sufficiently accurate to allow efficient control of foundry sands.

By the use of these methods it is possible to obtain a complete analysis of all inhibitors including sulphate in less than 2 hours by a single operator, if the precipitation of fluosilicate has been allowed to stand overnight.

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DISCUSSION

Presiding: DR. N. E. WOLDMAN, Eclipse Aviation-Pioneer Instrument Div., Bendix Aviation Corp., Bendix, N. J.

Co-Chairman: B. D. CLAFFEY, Gray Iron and Aluminum Div., General Malleable Corp., Waukesha, Wis.

GARNET P. PHILLIPS¹: (*written discussion*) While this paper, no doubt, will be of real assistance to those responsible for control of foundry sands, in going over the material, one phase is not clear: Moisture is determined at 90-95°C. (194-203°F.), which is slightly below the boiling point of water, whereas the usual procedure is to make this determination at slightly above the boiling point of water. I presume this is done because of the possibility of loss of other materials in the sand, at temperatures above the boiling point of water. Perhaps the author would care to elaborate a bit.

MR. CRAMER: (*author's closure*) Mr. Phillips is correct in assuming that the samples for moisture content were dried below the boiling point of water to prevent loss of other constituents. Sublimation of sulphur becomes appreciable at temperatures above 100°C. This precaution was taken to prevent loss of sulphur entering the moisture determination and to protect subsequent sulphur determination, should the same sample be used in this procedure.

¹ International Harvester Co., Chicago, Ill.

Core Sand Reclamation at Elevated Temperatures

By D. L. LONGEUVILLE* AND O. JAY MYERS*, CINCINNATI, O.

1. The company, with which the authors are connected, has been reprocessing core sands in its foundries for more than a year. These sands are reclaimed by burning out the binding materials, thereby restoring the sand to its original unbonded state. This saving of material, time, and expense has led this organization toward self-sufficiency in one of the most vital constituents of the foundry industry.



FIG. 1—CORE SAND PRIMARY CLASSIFICATION UNIT.

2. New sand is fed from hopper cars into bins by a series of conveyors and elevators. Necessary binding materials, water, and inhibitors are added at the mixers. After proper mulling, the sand mixtures are discharged into trams and carried to the core room. Cores are made, baked and assembled. The molds are poured and the castings knocked out.

* Wright Aeronautical Corporation.

NOTE: This paper was presented at a session on Plant and Plant Equipment at the 47th Annual Meeting and Second War Production Foundry Congress, St. Louis, Mo., April 30, 1943.

RECLAMATION PROCESS

3. Broken pieces of core resulting from the knock-out operation are classified by a trommel (Fig. 1). Provisions have been made here for the separation of iron chills, wires, and arbors. The small amount of non-ferrous refuse is segregated by hammer screens situated on the top of this unit.

4. The used core sand is next discharged from a chute to the rear end of the main rotary kiln (Fig. 2). This unit is well lined with refractory brick and rotates at a slow speed. The rotary motion and slight angle of the kiln cause the sand to flow to the front of the kiln, where it is subjected to a thorough fire cleanse at a temperature somewhat below the fusion point of silica. Directly under the burner, the sand drops down another chute and into the cooler (Fig. 3). This rotary dryer serves to bring the reclaimed material to a temperature sufficiently low so that it may be fed to a rubber belt conveyor. The fine debris joins the reclaimed sand, and both are carried to storage bins.

5. All of these units form a complete cycle, and should any of



FIG. 2—VIEW OF KILN FROM FIRING END.



FIG. 3—VIEW OF SAND RECLAMATION UNIT.

them fail, much damage would be done to the others. For this reason, an elaborate electrical control system (Fig. 4) has been installed, which would automatically shut down the whole system and sound an alarm, should any unit fail.

6. In making cores with the reclaimed sand, the same procedures may be followed as with new sand. Mixtures are identical. Although laboratory tests show that new sand has slightly better physical properties than well-controlled reclaimed sand, the differences are so insignificant that there is no danger in using the reclaimed material in place of new sand.

LABORATORY INVESTIGATION

Screen Analyses

7. An attempt was made to determine the reason for the lower physical properties of the reclaimed sand. Routine testing revealed a higher percentage of fines in the reclaimed material than in the new sand. Results of screen analyses are shown in Table 1 while Fig. 5 shows the distribution curves.

Table 1

SCREEN ANALYSES OF NEW AND RECLAIMED SAND

U.S. Series Screen No.	Per Cent Retained	
	New Sand*	Reclaimed Sand†
40	0.68	3.94
50	16.00	14.80
70	35.32	26.76
100	31.10	26.00
140	12.00	14.92
200	3.64	8.00
270	0.64	2.54
Pan	0.44	3.20
Fines	4.72	13.74
Total	99.82	100.16

Chemical Composition

8. Results of analysis are shown in Table 2.

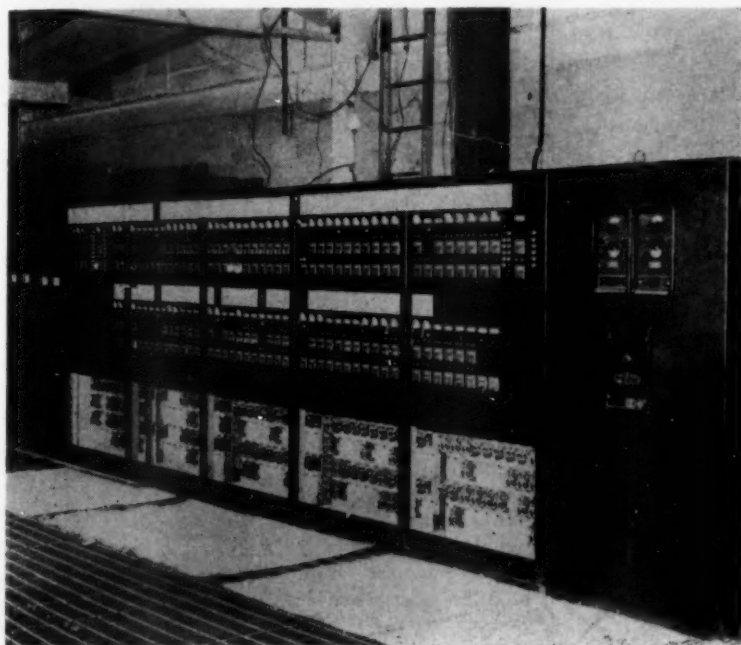


FIG. 4—CONTROL PANEL OF SAND RECLAMATION UNIT AND CONVEYOR SYSTEM.

* Figure 6.

† Figure 7.

Table 2

CHEMICAL ANALYSIS OF NEW AND RECLAIMED SAND

	<i>New Sand, per cent</i>	<i>Reclaimed Sand, per cent</i>
SiO ₂	99.7	99.5
Fe ₂ O ₃ + Al ₂ O ₃	0.16	0.29
MgO	0.10	0.08
CaO	Trace	0.17

9. These results show the differences in chemical composition to be so slight that the physical properties of the sand mixtures would not be influenced greatly. Silicon dioxide content of both the new and reclaimed material was essentially the same. Iron and aluminum oxide were slightly higher in the reclaimed sand. Calcium and magnesium oxides were of the same order of magnitude. The increase of the iron oxide, upon reclamation, may be caused by iron pickup from chills.

Microscopic Examination

10. The sands were examined under a low power binocular microscope (Figs. 6 and 7) to determine whether the grain shapes could have any influence on the physical properties. Observations of reclaimed sand are shown in Table 3.

Table 3

MICROSCOPIC EXAMINATION OF RECLAIMED SAND

<i>U.S. Screen No.</i>	<i>Description of Grain</i>
+ 30	Well-rounded milky to clear quartz grains. Occasional coating of Fe ₂ O ₃ .
+ 40	Homogeneous milky round quartz. For compound grains.
+ 50	Round to subangular quartz. One to two iron-tinted grains. Much more angular than + 40.
+ 70	Subangular to round quartz grains clear to milky in color. Grains homogeneous.
+ 100	Angular to subangular quartz. Iron-stained grains much more prevalent here (Fig. 7).
+ 170	Angular milky quartz. Impurities few.
+ 200	Clean angular quartz grains.
+ 270	Same as 200.
Pan	Same as 200.

11. The apparent gradation from round to angular quartz grains revealed that the upper screens retain the round-grained

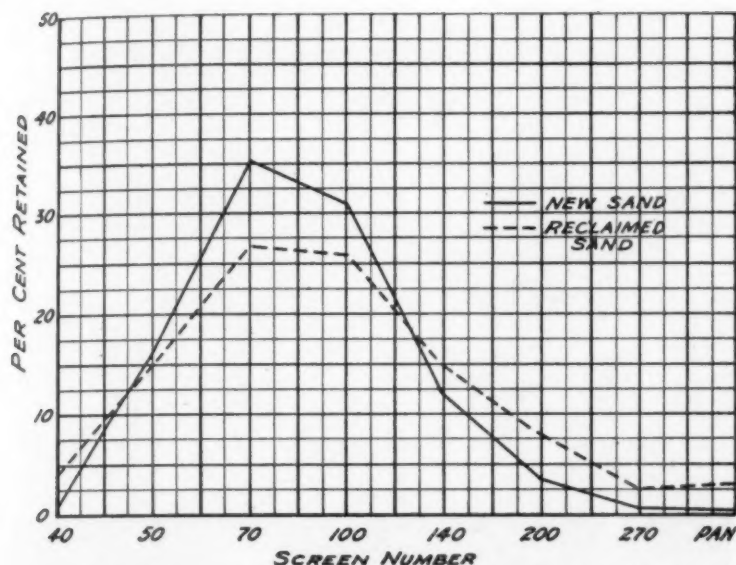


FIG. 5—COMPARATIVE SCREEN ANALYSIS OF NEW AND RECLAIMED SAND.

sand used in most of the mixes, while the lower screens catch the angular debris. Other than this, the reclaimed material is similar to the new sand.

PHYSICAL PROPERTIES

12. Several sand mixtures were made in the sand laboratory to obtain the physical properties of the reclaimed sand. Tests were conducted by A.F.A. standard test procedures. Identical mixes were made using new sand in place of the reclaimed material. A typical mixture used is as follows:

Sand, lb.	1000
Cereal Binder, lb.	3
Moisture, per cent	3
Core Oil, pt.	4½

13. A.F.A. standard cores were baked for 7 hours at 450°F. in the continuous-type ovens used in foundry production.

14. A comparison of the physical results is shown in Table 4.

15. Figure 8 shows the results of several hot-strength dilatometer tests on a sand mixture for core blowing. The reclaimed sand shows slightly better collapsing properties than the new sand.

Table 4
PHYSICAL PROPERTIES OF NEW AND RECLAIMED SAND

<i>Properties</i>	<i>New Sand</i>	<i>Reclaimed Sand</i>
Tensile Strength, lb. per sq. in.	164	133
Transverse Strength, lb.	36	30
Scratch Hardness Number	65	65
Dry Permeability	100	84
Green Permeability	92	68
Green Compression Strength, lb. per sq. in.	0.65	0.75
Fines, per cent	5.32	16.90
A.F.A. Grain Fineness No.	70	84

Tests were conducted at 1200°F. Specimens were baked for 2 hr. at 450°F.

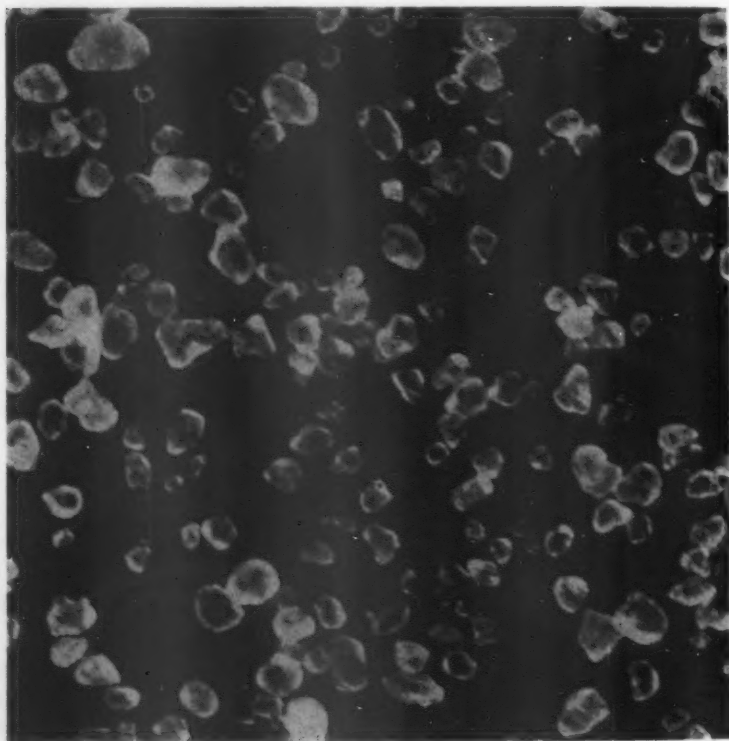
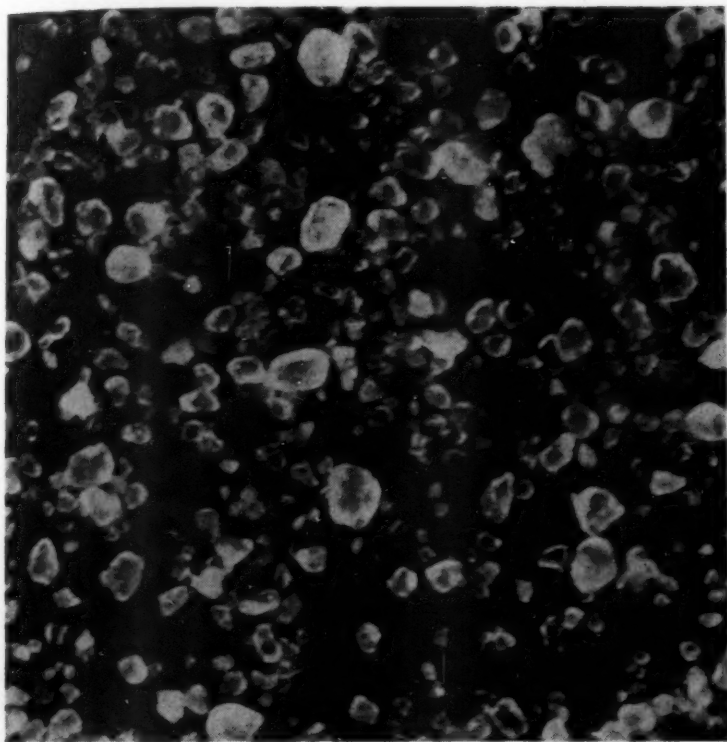


FIG. 6—NEW SAND. MAGNIFICATION, $\times 20$.

FIG. 7—RECLAIMED SAND. MAGNIFICATION, $\times 20$.

CONCLUSIONS

16. From comparative test results of new and reclaimed sand mixtures, as shown in Table 4, using the same amount of binding material, the following conclusions may be drawn as to the properties of reclaimed sand:

1. Lower tensile and transverse strengths.
2. Lower permeability.
3. Higher green compression strength.

17. These variations probably result from the fine material in the sand, rather than from any deleterious effects of the reclamation processes. Should it become necessary, it would be possible to eliminate most of the fine material and approach the same physical properties as the new sand.

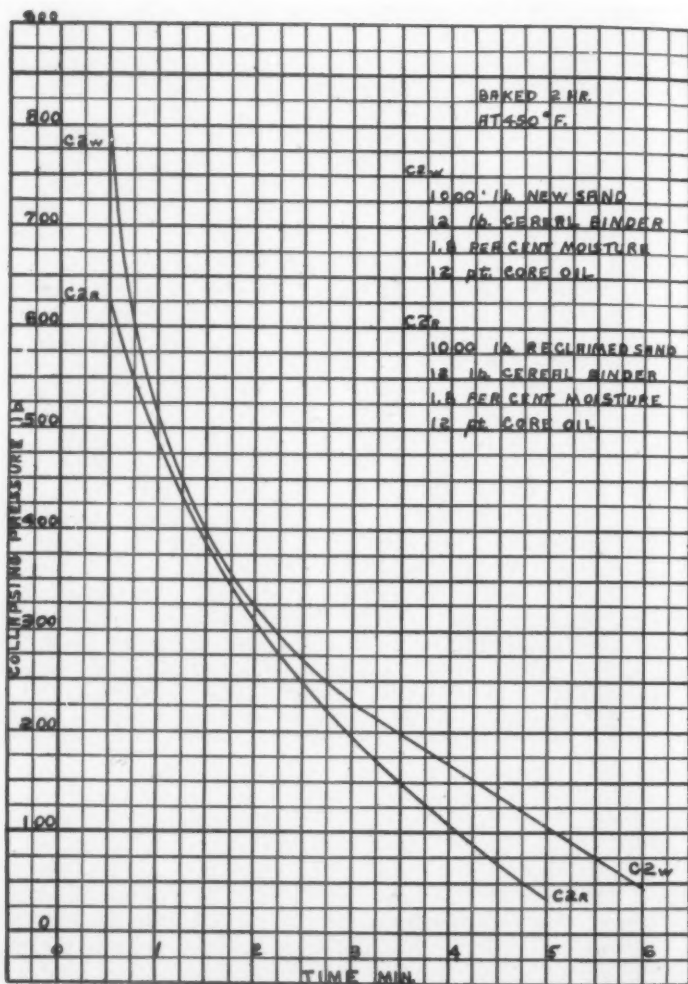


FIG. 8—HOT-STRENGTH DILATOMETER TEST ON SAND MIXTURE FOR CORE BLOWING.

ACKNOWLEDGMENTS

18. The authors desire to acknowledge the cooperation and courtesies shown them by the personnel of the Wright Aeronautical Corporation. Appreciation is also due to Robert Kattus and J. L. Potts for their aid in carrying out the tests and drafting the figures.

(For discussion, see page 210)

Thermal Process of Core Sand Reclamation

BY W. L. HARTLEY*, Chicago, Ill.

1. Used core knock-out sand is now being successfully reclaimed, for re-use as new sand, by the thermal process.
2. Installations are in production at Wright Aeronautical Corp., Lockland, Ohio, Buick Motor Co., Flint, Mich., and Ford Motor Co., Dearborn, Mich. Others are in process of installation.
3. It is a recognized fundamental among foundrymen that good castings and low scrap losses go hand in hand with closely controlled sand. The War Program has created an enormous increase in the use of cast metals of all kinds, with a resultant huge demand for classified sands from selected pits, the supply and transportation of which is a vital problem. Therefore, the importance of a successful sand reclamation process is paramount.
4. The major consumption of new sand, in all types of foundries, is in the making of dry sand cores. With few exceptions, new sand has been universally used for this production. Therefore, a successful reclamation process must approximate new sand results and produce a uniform sand.
5. The thermal method of sand reclamation is the first commercial development in the foundry equipment field to meet such requirements. While checking the action and performance of a rotary dryer we discovered the possibility of entirely renovating the used sand, even restoring its natural color, by exposing it to temperatures above 1000°F. This action was followed by operating tests, with results that led to the practical development of a complete thermal method of foundry sand reclamation. This high temperature process was developed and proved practical to the point where patent applications covering the process were justified.
6. The essential units of the thermal sand reclamation system are a high-temperature rotary kiln and a cooler, with essential burners, fans, dust collector and automatic controls.
7. Operation consists of granulation of knock-out sand lumps and uniform delivery to a rotary kiln, in which the temperature is maintained sufficiently high to heat the sand grains within a range of 1000 to 1500°F. The temperature indicated, along with the

* Link-Belt Co.

NOTE: This paper was presented at a session on Plant and Plant Equipment at the 47th Annual Meeting and Second War Production Foundry Congress, St. Louis, Mo., April 30, 1943.

abrading action of the rotary kiln, removes the carbonaceous and other foreign matter adhering to the sand grains by burning or vaporizing, as the case may be, and the resultant sand is as clean, and in some cases cleaner, than the original new sand, when only oil binders are used in the sand mix.

8. When clay binders are used, it will be found some dehydrated clay particles adhere to the sand grains after the reclaiming process. We believe that such sands should be dry milled in combination with a controlled air blast to remove the fines.

9. Operating experience may prove that dry mulling for final cleaning may not be necessary. However, laboratory tests indicate that this operation is essential in the production of sand for smooth dry sand cores, and in minimizing the use of re-bonding materials. Most laboratory and operating tests, to date, show that cores made from sand reclaimed by the thermal method have equal or better physical properties than do cores made from new sand.

10. Many castings are produced today with so-called synthetic sands, using as a base, high grade, classified silica sands, the Illinois-Ottawa District being one source for such sands. The cost to foundries of silica sands from that district varies according to freight rates in different sections of the country, but is seldom less than \$3.00 per ton delivered to foundries in the Illinois District; \$5.00 to \$6.00 per ton in the Eastern District, and as high as \$12.00 per ton on the Pacific Coast.

11. Average steel foundry operations generally will require around one ton of new sand per ton of good castings produced, and many shops will use more. Another tangible cost item is the disposal of used sand which will generally run between 50 cents and \$1.00 per ton.

12. Installation of a thermal reclamation system should prove profitable for steel foundries producing 40 to 50 or more tons of good castings per day, heavy gray iron shops producing 50 to 60 tons or more per day, and with aluminum and other types of foundries making castings from all dried sand core work. Operating results of existing installations show substantial savings by the use of this system, as the cost of reclaiming is but a fraction of the cost of new sand.

13. Cost of reclamation per ton of sand will vary with capacity of unit and tonnage handled and accounting practice. Following is a liberal cost outline:

Fuel-oil at 6 cents per gallon	0.60
gas at 48 cents per M.	
Labor—one man at \$1.00 per hour	0.34
(based on 3 tons per hr. capacity)	
Power—at 1 cent per kwh.	0.20
Maintenance—(estimate) 10 cents per ton	0.10
Depreciation—(estimate) 20 cents per ton	0.20
Reclamation—cost per ton of sand	\$1.44

14. The high temperature rotary kiln is a steel shell drum rotating on machine finished trunnions, the shell being lined with refractory brick. Continuous operation of the kiln at a uniform temperature is important in the life and low maintenance cost of the refractory brick lining in the larger units.

15. Units are available with capacities of from one-ton up to 10-tons per hour, with cost varying, according to size, from approximately \$20,000.00 to \$60,000.00.

16. In addition to the economies of this process, operating results show improved sand control as a result of the uniform products obtained. Screen analysis of the reclaimed sand can be controlled within narrow limits by regulation of exhaust velocities from the cooler.

(For discussion, see page 210)

DISCUSSION

Presiding: JAMES THOMSON, Continental Roll and Steel Foundry Co., East Chicago, Ind.

Co-Chairman: H. W. JOHNSON, Northwestern Foundry Co., Chicago, Illinois.

M. V. CHAMBERLIN¹: Mr. Myers, in the process of core sand reclamation you describe, I wonder what effect types of binders have had on the reclamation process. I refer particularly to the urea-formaldehyde type.

MR. MYERS: We have not been running enough sand containing urea-formaldehyde type binder through production to be able to give you an answer to that question. We have only done experimental laboratory work with that type of binder.

JOHN HOWE HALL²: Has sand from cement molds been put through this high temperature process of reclamation?

MR. HARTLEY: That has been discussed and is under consideration, but there are no operating experiences or even tests.

A. C. DEN BREEJEN³: Are all these installations on non-ferrous sands, and do you have any installations on gray iron and steel?

MR. HARTLEY: The installations now in operation are all on aluminum + magnesium sands using straight oil binders. There is an installation in the General Steel Castings Corp., Madison, Ill., that is now in process of construction and should be in operation within the next month or so. From that installation, we will obtain our first production results on steel foundry sands. We have run many tests on steel foundry sands which indicate very successful and satisfactory results.

MR. DEN BREEJEN: What about the gray iron and steel men who have molding sand adhering to their castings after they have been shaken out? Such sand usually contains clay. What would happen if sands containing clay were introduced into a system such as you advocate, in which you use high temperatures in burning off the carbonaceous coating?

MR. HARTLEY: There are a good many steel foundries that use a clay binder along with cereal binders. That is true of heavy gray iron. As to clay in the molding sand, the clay, which has been mulled around the sand grains, after it has passed through the mold, is dehydrated and calcined on the sand grain. After such a sand comes from the reclaimer, these sand grains have a fuzzy appearance because of the dehydrated clay. For such sands, we recommend dry mulling with an air blast passing through the sand. The dry mulling scarifies the sand grains, smooths and cleans them, and the particles of dehydrated clay will be carried off by the air stream to dust collectors.

MR. DEN BREEJEN: What space would a reclamation system of that type require following crushing and screening of the knockout sand?

¹ Dow Chemical Co., Midland, Mich.

² General Steel Castings Corp., Eddystone, Pa.

³ Hydro-Blast Corp., Chicago, Ill.

MR. HARTLEY: That would vary with size of units. The 10-ton per hour capacity units require approximately 20 ft. by 70 ft. in plan, about 25 ft. high. A 3-ton per hour unit requires a space about 12 ft. wide by 40 ft. long and perhaps 20 ft. high.

F. S. BREWSTER¹: About this pre-treatment of cores. Are they partly broken up and then put over a magnetic separator?

MR. MYERS: The cores are shaken out over a shaker, and they are crushed. The sand enters the rotary kiln as a completely crushed product. Knock-out sand is passed over magnetic pulleys at one or two points.

MR. BREWSTER: What equipment is necessary to granulate the core sand?

MR. HARTLEY: We use breaker screens for the primary breaking. Some are using jaw crushers for primary crushing of the large cores; others are using revolving breaker screens which take the material down to $\frac{3}{4}$ -in. That material then is passed over vibrating screens for finer screening of 20 to 30 mesh, which gets the material down to the proper grain size. The $\frac{3}{4}$ -in. sand is passed through hammer mill crushers for granulation and, then again re-screened to insure a uniform product.

CHAIRMAN THOMSON: Is the screening equipment part of the installation cost or is that extra?

MR. HARTLEY: It is extra. Quite a few foundries have the so-called tipple equipment. Where they do not have it, the screening equipment would be essential in connection with the reclaiming unit because of granulation of sand lumps. Obviously, lumps of compound grains would require a much longer kiln or furnace to heat and disintegrate the lumps, so that it is simple engineering practice and economy to granulate the sand properly.

I might add, in that connection, that the quality of the reclaimed product could be reduced. Most installations have a final scalping screen after the cooler to insure a clean, uniform sand.

MR. DEN BREEJEN: Both Mr. Hartley and Mr. Myers made statements about the relative core strengths obtained by the standard A. F. A. method.

Mr. Hartley said such strengths were practically as good as when new sand was used. Mr. Myers found he had in his original sand 4.72 per cent fines. In his reclaimed sand, as it came from the reclamation unit, he had a percentage of 13.74 per cent. That means approximately 9 per cent or 9.5 per cent of fine material, which evidently is cutting down the strength of the cores.

The figures on tensile strength ran 165 compared to 132 lb. per sq. in. Is that with the fines in or with the fines removed?

MR. MYERS: The physical property tests I mentioned were with the fines in the sand. As we now have the fine materials, they fall on the belt and are returned to the bins with the rest of the reclaimed sand.

¹Dow Chemical Co., Bay City, Mich.

Provisions can be made to divert this fine material and, therefore, approximate new sand results.

As I said before, we have yet to better the tensile strength of the sand by using reclaimed material.

MR. HARTLEY: I have here some laboratory reports on grain fineness number of new sand and reclaimed sand from two different foundries. These were daily reports that were given me from these foundries. They run very close together. The sand fineness can be accurately controlled by controlling air velocities in the unit.

MR. MYERS: Those figures on fineness were on our pilot mill and not on the mill now being used in production. It was used in production for a while, but we are getting most of our reclaimed materials from new units.

J. C. PIERCE⁵: What percentage of core sand that is put into a reclaimer is recovered as useful sand?

MR. HARTLEY: We do not have any real accurate data on that. All I can give is estimates. We tried to make as careful a check as possible in two foundries. On aluminum sand, recovery seems to be better than 90 per cent; whereas in a check in the gray iron shop, recovery seems to be around 85 per cent.

MR. DEN BREEJEN: Is that good sand without fines or with fines?

MR. HARTLEY: That is based on the sand that goes back to the bins for re-use. We have units operating where, as Mr. Myers mentioned, we arrange a dust collector on this sand that he checked. They are returning the sand from a dust collector back to the bin. They thought they wanted the fines until the fineness rose and permeability went down. When that happened, the fines from the dust collector were diverted.

MR. DEN BREEJEN: What I am trying to get at, Mr. Hartley, is what is your percentage breakdown?

MR. HARTLEY: From the tests made at two foundries, they could not find any appreciable breakdown of sand grains. Now whether those tests were conclusive or not, I do not know.

If the temperature gets high enough to cause fusion of the sand grains, that is apparent immediately in the appearance and condition of the reclaimed sand. The microphotographs that Mr. Myers has show that quite clearly. We have burned sand where we have fused it. We know it can be done; in fact, it is easy to do. However, results prove that this sand can be thoroughly cleaned, carbon removed, without damaging the sand grains.

⁵ Hydro-Blast Corp., Chicago, Ill.

Fire Control in Magnesium Foundries

By R. I. THRUNE*, MIDLAND, MICH.

Abstract

As a result of a series of experiments and actual magnesium fire extinguishing experience, the magnesium foundry, with which the author is connected, developed the methods and selected the magnesium fire extinguishing materials found to be most efficient in controlling magnesium fires. Types of fire extinguishing materials adapted to the various magnesium alloy foundry operations are described. Dust collecting equipment, to be used in connection with casting finishing and grinding operations, is covered. Methods, special extinguishing equipment and materials, and preventive measures taken to combat the magnesium fire hazards encountered in magnesium foundry practices are given in detail. Reclamation of metal chips and safe disposal of fine dust is presented as a practical operation.

1. A natural expansion of the metal-working industry is occurring, as magnesium alloys are taking an increasingly important place as industry's lightest structural metal. Use of these ultra light alloys in the production of the weapons of war has accelerated the expansion of the magnesium industry. Efficient production, which is highly desirable at any time, is now an important patriotic duty. A knowledge of proper fire control in magnesium foundries is essential to the efficient production of castings.

SCOPE

2. It is the purpose of this paper to present the magnesium fire control aspects of the more important industrial practices which are being used with magnesium alloys. The methods discussed are recommended to all companies concerned with the safe and efficient fabrication of magnesium alloys.

3. Over a quarter of a century of industrial experience has proved that magnesium alloy fabrication can be conducted with safety when proper steps are taken to prevent the hazards present in the following situations:

* The Dow Chemical Co.

NOTE: This paper was presented at a Safety and Hygiene Session of the 47th Annual Meeting and Second War Production Foundry Congress, St. Louis, Mo., April 30, 1943.

(a) When sizable amounts of fine dust are produced, and are not properly handled, this fine dry dust can be a fire or explosion hazard, and if moistened with water it becomes even more dangerous. This is due to the fact that magnesium alloy dust reacts with water. When moistened with approximately 5 to 40 per cent water it is easily ignited by a spark or flame, and will burn violently after ignition.

(b) When the metal is heated to a molten state without adequate flux protection, it will oxidize readily and gradually take fire on the surface.

(c) When crucible failure permits the metal to run into a hot furnace setting, burning will take place readily in the absence of a cover of flux. This burning will be greatly accelerated if iron scale or brick dust, which are both reactive with burning magnesium, are present in the setting.

(d) When the metal is raised to temperatures approaching its melting point, or the melting point of some phase of the alloy, in the absence of a protective atmosphere, the metal will burn. This condition will exist during the solution heat-treatment of magnesium alloys if the permissible temperatures are exceeded.

4. These hazards, when properly recognized, provide a basis for procedures under which the metal can be safely handled. It should be noted that none of these hazards apply except when the metal is molten, finely divided, or overheated.

FOUNDRY OPERATIONS

Melting of Magnesium Alloys

5. Magnesium alloys are usually melted in cast or wrought steel crucibles set in a brick setting, and fired by gas or oil. Chloride base fluxes are used to prevent the molten metal from oxidizing. They must be sprinkled on as needed to maintain an unbroken film over the molten metal. The hazards in this process will occur chiefly on melting without flux protection, or in case a crucible fails and allows the molten metal to run into a hot setting. The safety practices used to prevent and control such accidents are discussed in the following paragraphs:

Furnace Construction and Operation

6. Refractories that react only slightly with burning magnesium should be used in building the settings in which the melting pot is heated. The pot setting should be cleaned at least once a week to

remove all iron oxide crucible scale and brick dust. These materials will react violently with the burning metal, and will not only accelerate its burning but may cause explosions which scatter the molten metal.

7. Another precaution to prevent a serious setting fire is the use of a setting so designed that any metal running into it from a pot failure will immediately flow out again into a prepared, dry, run-off container. This will cut to a minimum the amount of burning in the setting, and enable production to be resumed with the shortest possible delay. The hot metal in the run-off container can easily be covered with flux or a special extinguisher, such as graphite powder and organic liquid compound, or dry graphite powder, and recovered for further use.

8. Should the pot setting be so poorly designed that the molten metal stays in the setting and burns, it can be extinguished by flooding the setting with graphite powder-organic liquid compound by means of a special portable powder pump. If this special equipment is not available, regular melting flux may be thrown into the setting. The flux will usually retard the burning rate of the metal and confine the fire to the setting.

9. Master controls on all the fuel and air lines leading to a pot setting should be located in such a place that they may be shut off at any time without the necessity of going near the setting. A setting fire is hazardous, and should be approached only, when in the opinion of experienced foundry men, no danger of an explosion is present.

Crucible and Ladle Operation

10. Careful inspection of the melting crucible should be made at least once a week to find any weak spots. This inspection may be done by hammering and calipering the crucible, discarding any crucible that is shown to have thin spots.

11. If the outside of the melting crucible is sprayed with aluminum the oxide scale formation will be cut down considerably, and the safe useful life of the crucible increased. This is particularly true of wrought steel crucibles. Another method of reducing the oxidation of the outside of the crucible is the maintenance of the combustion mixture in the furnace setting so that the surplus of oxygen is kept at a minimum. Both of these practices for the prevention of crucible failures have been proved good foundry practice.

12. Fluxes used on magnesium alloys are hygroscopic at room temperature, hence ladles and other tools used to handle molten metal usually collect moisture when not in use. Visual inspection should not be relied upon to determine the presence of moisture. Therefore, as a routine step, all tools should be properly preheated before they are placed in contact with molten magnesium. Moisture pushed under the surface of molten flux or metal will cause an explosion which may be serious.

13. Handles and braces on the tools used with molten magnesium are usually constructed of tubes, to give both lightness and rigidity. It is recommended that great care be exercised in the construction of structural parts which will be immersed in molten flux or metal when in use. The possibility of using bars or structural shapes which are not enclosed should be considered, as this would eliminate the possibility of entrapped moisture developing dangerous pressures when the tool is under the surface of the molten metal or molten flux.

Casting Operations

14. No attempt will be made to discuss molding techniques other than mentioning that the molding sands should be of the type designed for magnesium castings. Special inhibiting agents, which are added to these molding sands, make it possible to pour molten magnesium into moist sand molds with no accompanying reactions. Great care should be taken to prevent the accidental introduction of foreign material of any kind, or of excessive amounts of moisture, into the mold. This precaution should be observed when the molds are being formed, and also during the time between the finishing of the mold and the actual pouring of the metal. Molds standing on the foundry floor should be covered to prevent material from falling into the sprues and risers. These precautions are necessary, since failure to observe them may result in violent burning of the metal in the mold, or even explosions which throw the metal out of the mold.

15. The molten metal should be carefully conveyed to the molds in mechanical conveyors, in hand ladles, or in crucibles on two wheeled buggies. Some of the large pour-offs are made from crucibles conveyed to the mold by an overhead crane.

16. It has been found that face guards, fire retardant clothing, and fire retardant, heat resistant gloves will provide general protection to melting and pour-off men in a magnesium foundry. Fire retardant clothing is usually made of heavy canvas, which has been

impregnated with a 15 per cent solution of di-ammonium phosphate. Protection of the feet and legs of the pour-off crew is very important, and special protection in the form of easily removable leather or fire retardant chaps is recommended.

17. Installation of easily operated deluge showers at strategic locations in the foundry is recommended for extinguishing clothing fires. They are much more effective than fire blankets for the control of a clothing fire started by molten metal.

CASTING FINISHING

18. Operations such as machining, chipping, sawing, rotary filing and grinding produce magnesium chips or magnesium dust, which will burn under certain conditions. The danger created varies indirectly as the size of the particles. Coarse magnesium particles do not present a special fire hazard such as that occasioned by fine dusts. However, they must be regarded as a fire hazard if not properly handled.

19. The practice found most satisfactory for the control of the hazard from coarse particles is simply that of good housekeeping around the machine that produces them. Operators are protected by smooth, fire retardant clothing, and are instructed to periodically brush off any metal particle accumulations before they become sufficiently large to create a hazard. Janitors sweep the floor regularly, and place the coarse particles in properly labeled covered metal containers.

20. Metal particles of the above type can be economically remelted, and proper care of them is recommended both as a safety practice, and as a means of conserving valuable metal.

21. While experience has shown that coarse magnesium metal particles produce no exceptional hazard, exactly the opposite is true of fine magnesium dust, and particular care is urged in its proper disposal. It is impossible, the writer believes, to define arbitrary limits which will separate the safe recoverable coarse particles from the dangerous fine dusts. It is the best practice to play safe in every case where subdivided metal is handled. It is certainly true that dust which has a tendency to float in the air should be considered very dangerous. Dusts which settle in a short time are also dangerous. Hence, the best rule is to prevent accumulations of metal particles in any working place. Attention has been called to the fact that all such metal particles must be kept free from water, because moist magnesium dust will burn more vigorously than will dry dust.

22. It is recommended that the dust produced by the grit blasting of magnesium castings be collected in a properly designed, liquid type dust collector, which will safely dispose of this hazard. Dust collected from the sand blasting of magnesium castings is, apparently, not flammable.

Machining, Sawing, and Rotary Filing

23. High speed band saws are used for the removal of gates, sprues and risers. Ordinary machining operations frequently are used for the rough finishing of magnesium castings. Rotary filing is used to remove fins, and for generally smoothing the casting surface. A special hazard is connected with these processes when very fine turnings are produced. These fine chips will burn readily, and may become ignited by:

(a) Frictional heat or sparks caused by improper machining practice, or from sparking material lodged in the metal being machined.

(b) Fires from an outside source.

24. The following safe machining practices should be carefully observed:

1. Keep tools very sharp and ground with adequate clearance. If proper procedures are followed it will be found that magnesium is very easily machined.

2. Take as heavy cuts as are practical.

3. Always back tool off the work when cut is finished.

4. If a coolant is needed, use an all mineral oil coolant of proper viscosity, so that it will wet and cool the work. Water-oil emulsions are dangerous because of the reaction between water and finely divided magnesium.

5. Do not allow finely divided metal to accumulate on or under the machine.

6. Have an adequate supply of a magnesium fire extinguisher instantly available at the work place. Demonstrate its use so that all operators are capable of applying it properly.

7. Keep open flames or hot sparks away from finely divided magnesium at all times. Warn welders of this hazard. Smoking at the work place should not be allowed.

8. Collect the finely divided metal from the machines that produce it and place in dry, plainly labeled, covered iron containers. Do not allow large amounts to accumulate in the machine shop. Store containers in a plainly marked, non-com-

bustible building. A sufficient supply of an effective fire extinguisher should be available at the storage place. Warn firemen of the danger of the use of water on burning metal.

HANDLING OF SCRAP METAL

25. Clean magnesium alloy scrap of all kinds, except the fine dusts, can be safely and economically remelted into ingot metal. This scrap should be carefully collected and kept dry and clean, so that a maximum efficiency can be realized in the recovery process. Solid, bulky scrap can be remelted directly in the foundry, after cleaning free from sand and preheating to insure complete dryness.

26. The presence of moisture in finely divided scrap reduces considerably the percentage of metal that can be recovered. If the amount of water in the scrap is above a few per cent of the weight of the metal, there is great danger that a violent fire will occur when the metal is melted. Wet chips are about the same class of hazard as wet grinding sludge, and should be disposed of in a similar manner.

27. The presence of a mineral oil coolant, with a high flash point, on the finely divided scrap reduces the fire hazard because the metal is harder to ignite when wet with oil. If a fire is started the fumes from the oil have a smothering effect on the metal fire. The excess oil should be drained or centrifuged from the chips before they are remelted.

28. Though the process of recovery of scrap is not extremely difficult, it should not be attempted without special instructions.

GRINDING

29. Grinding with disc grinders, standard abrasive wheels or glued-up buffing wheels, is used for the rough snagging of castings, and for further smoothing of surface after rotary filing. The dust produced is definitely hazardous, and suitable methods must be provided for its safe collection and disposal. The study of the problem of how to best collect magnesium grinding dusts has resulted in the development of satisfactory equipment by many manufacturers.

30. A good magnesium dust collector should do the following things:

1. Remove all dust from the grinding area as soon as it is formed.

2. Render the dust harmless by precipitating it in a liquid, such as mineral oil or water, before it can collect in sufficient concentration to produce an explosive air-dust mixture, or collect on areas where it may burn if ignited.

3. The ducts between the grinding area and the precipitating area should be short and as straight as it is possible to make them. These ducts should be kept clean of any accumulations of dust by the regular operation of the collector.

4. The dust, after precipitation, should be kept under a layer of liquid until removed for final disposal.

5. All the operating parts of the collector and grinder should be interconnected, so that the dust cannot be produced unless a means for its safe collection is in operation.

31. Magnesium dust collectors become hazardous when they allow flammable dust to:

1. Collect in explosive air-dust mixtures.
2. Deposit in a porous layer which will burn violently when ignited.
3. Accumulate with about 20 per cent water so an easily ignitable, violently-burning mixture is produced.

32. The use of dust collecting systems that allow any of the above conditions to develop should be discontinued at once. The use of an unsafe collector is more dangerous than the use of no collector at all.

33. At the present time most of the magnesium dust collectors in industrial use are operating with water as the dust precipitating medium. The use of a straight mineral oil as a precipitating medium has been studied, and some commercial dust collectors are now using it. Oil has these advantages over water:

1. It wets magnesium dust more readily than does water.
2. There are no critical mixtures of oil and magnesium dust which accelerate the burning rate of the dust. Furthermore, magnesium dust wetted with oil burns with less violence than does dust that is dry or wetted with from 5 to 40 per cent water.

Disposal of Grinding Dust

34. There are no known methods of safely and economically remelting the fine grinding dust precipitated in a wet dust collector.

35. The methods recommended for the disposal of the dust are as follows:

1. The wet dust sludge is completely mixed with 5 parts of sand and buried. This procedure is satisfactory if the amount of sludge is not very large, and if sufficient inert refuse material is mixed into the dumping area. However, large foundries have found that the disposal, by burying, of three or four cu. yd. of wet sludge each day will develop some trouble, as evidenced by fires and gas explosions in the dump area. It is supposed that much of the trouble is due to an improper mixing of the wet sludge with the sand.

If a large quantity of grinding sludge is developed, or if the dumping facilities of the foundry are limited, it is recommended that the sludge be burned.

2. The wet sludge is burned on an outdoor area capable of withstanding the heat produced. It must be remembered that the burning properties of magnesium sludge wet with water are rather peculiar in that this material, when wet with over about 50 per cent water, can not be ignited, but when wet with about 25 per cent water is easily ignited and burns violently. For this reason wet sludge should not be burned in a conventional incinerator.

36. The burning area may be a layer of fire brick or hard burned paving brick, set on an angle so that it drains properly. The wet sludge should be spread at a thickness of three or four inches. A layer of ordinary burnable refuse is placed over the wet grinding sludge and ignited. The burning refuse supplies enough heat to dry and ignite the top layers of the sludge. Result of the above procedure is that the entire pile of sludge is slowly burned as it dries. The burning refuse acts as a shield, absorbing much of the heat and light from the burning metal dust.

37. It is recommended that great caution be exercised in the burning of this sludge. It must always be remembered that fine magnesium powder, wet with the critical amount of water, will burn with violence. This is due to the fact that the burning metal decomposes the water and combines with the oxygen of the water.

38. The critical percentage of water varies somewhat with the mesh of the powder. Usually, 40 to 50 per cent water is enough to prevent burning, and 5 to 40 per cent results in a mixture which will burn violently. These critical mixtures are also easy to ignite.

HEAT-TREATING OPERATIONS

39. Heat-treatment of magnesium alloys, even at the maximum temperature, which for some alloys is up to 780°F., does not involve any fire hazard if the temperature schedules are properly maintained. It is only when the temperature, locally or generally, exceeds the recommended level that surface burning of the casting occurs. This burning may continue and finally develop enough heat to melt the casting, and free burning will then result. Damage that may result from a fire in a heat-treating furnace filled with castings is considerable, and means of preventing and controlling such fires have been developed.

40. The precautions to be discussed refer only to the solution heat-treatment cycle, and not to the aging heat-treatment, which is done at 350°F. No protective atmospheres are necessary at this temperature.

Fire Prevention

41. The following fire preventive methods have been found effective:

1. Surfaces of castings should be free from grindings and sawings, which would be likely to ignite in the heat-treating furnace. Likewise, furnaces should be kept clean and free from scale, which would tend to support combustion should it come in contact with burning metal.

2. Adequate temperature measurement and heat distribution devices should be installed in the furnace that is to be used to heat-treat magnesium alloy castings. Complete surveys of the furnace should be made to determine the actual temperatures. This is both a fire prevention procedure and a necessary step in the efficient heat-treating of castings.

3. Automatic devices should indicate any abnormal temperature rises. Portholes for the observation of possible fire conditions have been installed on some furnaces. These are for the detection of small fires that have not developed sufficient heat to make their presence known through a temperature rise observable on the recording instruments.

4. Installation of devices to insure the presence of at least 0.7 per cent of sulphur dioxide in the atmosphere of the furnace is recommended. It has been found that about 0.7 per cent of SO_2 will inhibit surface oxidation to a great extent, and prevent fires from starting. Temperatures might then, in an emer-

gency, rise above those necessary for good heat-treating without any fires resulting.

42. However, SO_2 must not be considered as an extinguisher of burning magnesium. It is a useful oxidation inhibitor at the temperatures recommended for heat-treatment. However, if the metal is freely burning it is violently reactive with SO_2 . The SO_2 is decomposed, and the sulphur, as well as the oxygen, combines with the magnesium in heat producing reactions.

Extinguishing Heat-Treating Fires

43. Because a fire can develop in a heat-treating furnace, it is recommended that an adequate fire extinguisher be available.

44. The extinguisher recommended for the best control of magnesium fires in a heat-treating furnace is a graphite powder and organic liquid compound applied with a machine that pumps the compound through a hose and nozzle. This "fire engine" enables the fire fighter to direct a stream of the extinguisher directly on the fire area. The furnace door should be opened to allow the fireman access to the entire rack of castings. As soon as the fire is under control the rack of castings should be removed from the furnace. The final extinguishing of the fire can be done outside of the heated furnace. This makes extinguishing much easier, because it removes the castings from the heat of the furnace walls and tends to reduce the clean-up problem on the furnace. However, it is cautioned that the rack of metal should not be removed until the fire is thought, by experienced operators, to be definitely under control. If it is thought desirable, the fire can be completely extinguished in the furnace.

EXTINGUISHING MAGNESIUM FIRES

45. Our recommendations on extinguishing procedures are based on a long series of experiments, and some experience with actual fires. This experience has included the use of fluxes, dry powder extinguishers, powdered pitch mixtures, heavy hydrocarbon oils, both gas and liquid sulfur dioxide, nitrogen, and carbon dioxide gas.

46. The gases used are all ineffective, because they support the combustion of burning magnesium. The hydrocarbon oils are effective on small open fires, and on small fires in tight furnaces, but their general use on large fires is dangerous, because of the large amount of volatile and inflammable gases they produce when

heated by the fire. Pitch and pitch mixtures, though effective on small fires, are not recommended for large fire control for the same reason. The secondary fire produced by the use of a flammable extinguisher might become more dangerous than the original magnesium fire. Melting fluxes, or extinguishers of similar composition, are not recommended for the following reasons:

1. Their hygroscopic properties make it difficult to store them in easily accessible containers at strategic locations.
2. Fluxes applied to burning metal in a heat-treating furnace would fuse and flow to the bottom of the furnace. The work of cleaning the solidified flux from the furnace would be a major undertaking.
3. The corrosive action of fluxes at room temperatures makes it inadvisable to use them in fire extinguishing apparatus.

47. The conventional fire extinguishing materials such as water, vaporizing liquids, foam type, carbon dioxide gas and carbon dioxide producing powder, are violently reactive or not effective when applied to burning magnesium. Their use is not recommended on industrial magnesium fires. Because the use of an improper extinguisher on a magnesium fire is much worse than no extinguisher at all, it is recommended that this fact be clearly demonstrated to all workers in a plant using magnesium.

48. There are several approved brands of fire extinguishers which are effective on magnesium fires of a limited size. These extinguishers are very effective if used within their limited fields, and these remarks are not to be construed as a general condemnation of these extinguishers. A small magnesium fire is easily extinguished by many types of materials. It is when the fires reach considerable size, and develop an intense heat, that special care should be exercised in the selection of the extinguisher used.

49. An incipient magnesium fire on a dry non-combustible surface is easily extinguished by a covering of sand, talc, asbestos, or other compounds with a similar chemical formula. However, when these compounds are applied to a freely burning magnesium fire they usually accelerate that fire. This apparently inconsistent result has led to the conclusion that a magnesium fire, once fairly started, is not extinguishable.

50. A study of magnesium fires has revealed that the accelerating action, which appears when certain materials are applied to a fire, is due to the combination of the burning metal with certain

elements in the compounds. These elements combine with the magnesium in heat-forming reactions, and the fire often burns more intensely under the cover of the so-called extinguisher than it does when open to the air.

51. If a freely burning magnesium fire is properly attacked by a true magnesium fire extinguisher, it will be extinguished as any other fire is extinguished when attacked by a proper extinguishing agent.

52. A special extinguishing compound, which is effective for general use on magnesium fires, is marketed under a trade name by the Pyrene Mfg. Co., Newark, N. J.

53. This compound is effective because it provides both a cooling effect due to its graphite content, and also a smothering gas due to the volatilization of a liquid mixed with the graphite. The extinguisher is essentially a non-burning material, and no secondary fires result from its use on a large magnesium fire. Graphite compound does not fuse, so the clean-up problem is simply that of removing the dry powder. The graphite powder, which forms the bulk of the compound, is completely inert to burning magnesium, and is also a very good conductor of heat. This powder is very stable in storage and is easily handled in the special extinguisher pump developed by the St. Regis Paper Co., Oswego, N. Y. It does not interfere with recovery of residual metal after the fire.

54. This discussion of the extinguishing compound is presented as a review of the requirements a material must meet to be considered a good magnesium fire extinguisher, safe for use on fires of any size.

55. Of importance, equal to the availability of a good extinguisher, is knowledge and skill in its application. A definite training for the workers who may encounter a magnesium fire should be included in the safety program of every plant.

56. Supervised demonstrations should teach the following facts about fire control:

1. Knowledge of how a magnesium fire burns by the observation of a fire.

2. Knowledge of how the metal fire reacts when conventional fire extinguishing materials are applied to it.

3. Knowledge of how to extinguish a magnesium fire on a dry, non-combustible surface, and on a wet or combustible surface. This is done on a dry non-combustible surface by merely covering the fire with a sufficient amount of a satisfactory mag-

nesium fire extinguisher. The actual method of application recommended by the supplier of the extinguisher should be followed.

On a wet, or combustible surface, the fire must be removed from contact with the surface, if it is to be extinguished. This is done by covering the fire with a layer of the extinguisher and then pushing or lifting the fire on to a metal plate or a layer of the extinguishing powder. When the magnesium fire is completely surrounded by a non-reactive material, it will cease to burn, and soon cool below its ignition temperature.

4. Knowledge of how magnesium chips burn when dry, when wet with mineral oil, and when wet with about 25 per cent water, by weight. This is easily demonstrated, but care must be exercised because of the fast burning rate of the metal wet with water. Piles of fine magnesium metal chips should be provided. One should be dry, the second wet with a mineral oil, and the third wet with water equal to about 25 per cent of its weight. They should be placed on metal surfaces. About 5 lb. to a pile is sufficient. The piles should be carefully ignited, and the rate of burning will demonstrate clearly the danger present in wet magnesium fires. It is suggested that a fuse of dry chips be used to ignite the wet chips so that the demonstrator will not be burned by the flare up of the wet chips.

SUMMARY

57. If the simple precautions necessary for the safe handling of magnesium alloys are known and practiced, then there is no greater danger to the worker with magnesium than to any other metal worker.

58. The precautions necessary for the handling of molten magnesium alloys are those common to all melting practice: namely, proper crucibles and crucible settings, ample equipment to handle the metal without spilling, and proper molds in which to cast the molten metal. The foundry should be well ventilated, and the workmen should be provided with face shields and fire retardant clothing. There should be available an ample supply of protective agents to prevent the molten metal from oxidizing. The fact that the melting points of magnesium alloys are relatively low adds to the safety and convenience with which it can be handled in the molten state.

59 Fine dust produced by the grinding or polishing of mag-

nesium alloys is a definite hazard, but this can be taken care of through the use of proper dust collection equipment and proper disposal methods.

60. Hazard associated with the coarse dust produced by sawing or rotary filing of castings can be kept under control by good housekeeping.

61. Workers performing operations that produce finely divided metal should guard against the accumulation of metal dust in their clothing.

62. There is some hazard present in the machining of magnesium when fine shavings are produced. However, if proper machining procedures are followed, tons of castings can be machined with no trouble. If fires occur, they will indicate that proper procedures are not being followed.

63. An incipient magnesium fire, which has not developed enough heat to appreciably raise the temperature of the unburned metal and the surrounding area, can be extinguished by almost any thermally conductive material which is itself relatively non-combustible, and which does not contain freely available water, chlorine or oxygen. This includes a long array of materials, such as common sand, common salt, pitch, asphalt, heavy oils, magnesium fluxes, cast iron borings, and graphite powder.

64. As the size and rate of burning of a fire increases its chemical activity increases, and the number of extinguishers which are effective decreases. The extinguishers which do not produce heat-forming reactions with the burning metal, and are non-combustible at the temperature of the fire area, are effective on large fires. Only thoroughly tested extinguishers should be used to control large industrial fires.

65. When the known procedures for fire prevention and fire control are put into practice, the performance record of the plant will prove that the fire hazard in the commercial handling of magnesium alloys is minimized by proper control.

(For discussion, see page 234)

The Control of Magnesium Dust

BY JOHN M. KANE*, LOUISVILLE, KY.

INTRODUCTION

1. Magnesium dust is the proverbial exception, in many respects, when consideration is given to its control and collection. Had its use been expanded more gradually, the boiling down and digesting of various factors in dust control systems would have been more orderly, and much of the resultant confusion eliminated. As in most new processes, time and study were required to correlate the many ideas and proposed methods of dust handling suggested by concerns new to the field of magnesium fabrication.

2. Such correlation has progressed rapidly, and it is now possible to make some very specific comments on the fundamentals covering magnesium dust control.

3. The ease with which magnesium dust can be ignited is its critical characteristic. A small burning particle carried through an exhaust system can quickly ignite collected material in a dry dust collector, or accumulations in a poorly designed exhaust system. Burning of the accumulations proceeds so rapidly that flare-backs and pressures of explosive proportions can easily occur. This ease of ignition made accepted methods of handling other materials, equally as explosive, ineffective and unsafe practice for magnesium.

4. The generation of hydrogen from the reaction of magnesium particles and water also required consideration. While this reaction does occur in any collector using water as the collection media, the volume is small and readily vented to the surrounding air in a very dilute safe concentration. Magnesium in a flooded state, stored under water, cannot be ignited.

STAND-GRINDING, POLISHING, BUFFING

5. Grinding stands and polishing jacks produce large quantities of fine magnesium dust, which, if not effectively exhausted and collected, offer the greatest possibilities for fires of troublesome magnitude. Safe and effective dust control requires:

(1.) Exhaust volumes and velocities recommended for fer-

* American Air Filter Company.

NOTE: This paper was presented at a Safety and Hygiene Session of the 47th Annual Meeting and Second War Production Foundry Congress, St. Louis, Mo., April 30, 1943.

rous grinding by A.F.A. Recommended Good Practice Code and Handbook on Fundamentals of Design, Construction, Operation and Maintenance of Exhaust Systems, and State Codes. Where large castings are ground, larger than usual hoods may require increased volumes through larger branches to compensate for the larger hood opening.

Castings with recesses or pockets often accumulate fine dust on their inner surfaces during grinding, polishing or buffing. The air exhausted from the wheel hood will not pick up such protected accumulations, and it may be necessary to provide an auxiliary down draft grille, on which castings can be tapped to remove such accumulations.

(2.) Dust collector (Fig. 1) should be of unit type employing, the writer believes, water as a collecting media. Air moving equipment should be on the clean air side and the collected dust stored under not less than 6-in. of water. Unit collectors reduce to a minimum the possible damage to personnel and equipment by confining any fire to a restricted area. Long duct runs are eliminated, reducing the possibility of accumulations.

(3.) Collector should be located directly behind each grinding stand or polishing jack. Duct connections from hood to collector should be as short as possible. Recesses where dust could accumulate, such as traps in hood or duct, blast gates and dead-end caps must be avoided. Even in such short duct connections clean-outs should be provided if duct surfaces are not accessible

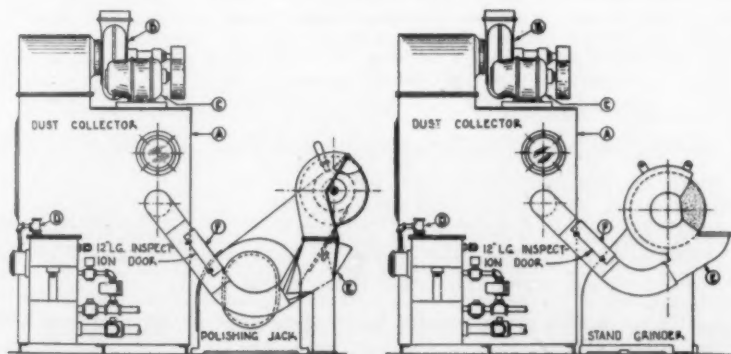


FIG. 1—DUST CONTROL UNITS FOR MAGNESIUM GRINDING, POLISHING, BUFFING. A—UNIT TYPE WET COLLECTOR WITH PROVISIONS TO STORE COLLECTED MATERIAL UNDER WATER; B—EXHAUSTER ON CLEAN AIR SIDE OF COLLECTOR; C—TOTALLY ENCLOSED MOTOR; D—LOW LEVEL SAFETY CUT-OFF SWITCH TO PREVENT OPERATION OF COLLECTOR WITHOUT WATER; E—NO TRAP OR RECESS IN HOOD TO ACCUMULATE MATERIAL; F—DUCTS SHORT, NO BLAST GATES OR DEAD-END CAPS.



FIG. 2—DOWNDRAFT MAGNESIUM GRINDING BENCH FOR FLEXIBLE SHAFT GRINDING, BURRING AND POLISHING. WATER RESERVOIR BENEATH WORK GRILLE. INTEGRAL WET DUST COLLECTOR AND CONTROL DEVICE TO PREVENT OPERATION WITHOUT SATISFACTORY WATER VOLUME. EXHAUSTER MOTOR TOTALLY INCLOSED. WORKING GRILLE AND TOOL REST OF WOOD TO PREVENT SPARKING.

for inspection. If installed, they should be on top side of duct, and conform closely to duct contour.

(4.) Motor on grinding stand or polishing jack should be interlocked with exhauster motor so that grinder cannot be operated unless air is exhausted from wheel hood.

(5.) Water from nozzles in hood or duct is not required with the unit collector system. Nozzles in hoods may cause damp zones in back of hood, where deposits will adhere. Such deposits could increase the hazard by partially drying out during a shut down period. Water in ducts complicates the dust collecting equipment, and requires considerable auxiliary equipment.

FLEXIBLE SHAFT GRINDING, POLISHING AND BUFFING

6. The fine dust from flexible shaft grinding, polishing and buffing operations must also be exhausted to reduce a potential hazard almost as great as that from the grinding stand or polishing jack. Such operations can be controlled by:

(1.) A ventilated bench (Fig. 2), grilled top with not less than 200 cfm per sq. ft. of gross working area.

(2.) Bench design must be such that dry particles cannot accumulate in hopper beneath grille, or on any ledges or hopper walls. Not more than four operators should be employed on one ventilated bench, and side shields should be provided to further isolate each operator.

Ventilated benches which incorporate a water reservoir directly beneath the bench and a wet type dust collector as an integral assembly, eliminate all duct connections and store the collected material under a safe head of water.

(3.) Where a water reservoir is provided under the work grille, an interlock between exhaustor motor and flexible shaft grinders is not essential, but is recommended. It prevents dispersion of the fine dust to the workroom by assuring exhaust ventilation at all times when the grinders are in operation.

FLEXIBLE SHAFT FILING

7. In many plants no exhaust ventilation is provided for flexible shaft filing where only coarse magnesium particles are removed. Particles in this range do not present the potential hazard of fine dust. Like chips from machining operations, the coarse particles do not burn at the violent rate of fine magnesium dust, and fires can be controlled by conventional magnesium fire extinguishers.

8. Such operations can be exhausted, using the same recommendations discussed for flexible shaft grinding, polishing, and buffing. The use of a ventilated work bench greatly improves house-keeping and undoubtedly increases production due to the improved working conditions, the elimination of time for frequent cleaning up of accumulated chips and the distraction caused by occasional fires in such areas. These factors can easily offset the loss in salvage value due to wet collection, as the quality and quantity of generated particles do not approach possibilities of chips from machining operations.

BAND SAWS

9. Band sawing can be placed in the category with flexible shaft filing. The particles are relatively coarse, and the operation has been safely handled without exhaust in a number of plants.

10. However, exhaust ventilation has distinct advantages. With the high cutting speeds used, magnesium particles are scattered over a wide area. Time lost in housekeeping and in extinguishing the not infrequent fires resulting from sawing operations, can quickly justify exhaust ventilation.

11. The same recommendations discussed for stand grinding, polishing, buffing apply. In addition to the conventional exhaust connection beneath the table, an auxiliary connection will be required to collect the flying particles that are not carried downward by the saw blade, where risers are cut at appreciable heights above the table.

OIL VERSUS WATER AS A DUST COLLECTING MEDIA

12. Magnesium dust collection methods discussed employ water as the collecting and storage media. Therefore, what the author believes to be a comparison of the features of a high flash-point mineral oil and water in dust collector service will indicate the respective advantages of each.

13. There is no reaction between oil and magnesium to liberate hydrogen. Any damp accumulations on collector surfaces stay oily and do not dry out. There is no critical mixture of oil and water where the burning of magnesium is accelerated. Oil may provide better quenching for any burning particles carried to the dust collector. Collected particles removed from the collector are coated with oil and can be more safely stored and disposed.

14. Considerable oil will be lost by entrainment and adherence to collected material, resulting in added operating expense. Oil vapors in the exhaust air may prevent recirculation of the cleaned air. Replenishments and use of a proper oil involves the human element. Dust collector cannot be easily drained to facilitate removal of collected material.

15. Experience over an extended period on a large number of unit type dust collectors employing water indicates that some of the advantages of oil may be more theoretical than actual. The amount of hydrogen generated is diluted well below any hazardous concentration, and is much lower than concentrations from pick-

ling and anodizing tanks. Water is inexpensive, of consistent quality, and provides an unlimited source for make-up. Danger of oil fires is eliminated. Most collectors using water can recirculate the cleaned air to the workroom, providing flexibility in equipment relocation.

16. On the basis of the above comparison, it is apparent that oil is a safe collecting media, but with the limited experience in the field and with the extensive satisfactory experience where water has been used, it would seem premature to recommend one over the other, or to imply that one is superior to the other for safe operation of dust collectors.

ABRASIVE CLEANING

17. Exhaust requirements for abrasive cleaning should follow the A.F.A. Code of Recommended Good Practices for Metal Cleaning Sanitation. Where the abrasive is sand, the bulk of the dust is sand fines and the magnesium content is too small to require special consideration.

18. Where metallic abrasive is used, the proportion of magnesium in the exhausted dust is appreciably higher, and the following precautions should be taken:

1. Dust collector should be of the wet type storing the collected dust under water.
2. Ducts should be free of dead-end caps or recesses where quantities of dry dust could accumulate.
3. Clean-out doors should be on the top of the ducts to eliminate accumulations. They can be spaced every 20 feet or less, and be provided with chained or hinged covers to serve as pressure reliefs in case of fire. Area should be not less than cross-sectional area of duct.

SAFETY PRECAUTIONS

19. On all dust collectors handling magnesium, the following precautions are suggested:

1. Totally enclosed motors should be used to prevent settlement of fine floating particles in motor windings.
2. All equipment should be grounded.
3. A protective device should be provided with the dust collector, which will prevent operation unless correct liquid flow

and proper liquid volume are maintained.

4. Equipment used for working magnesium must not be used for ferrous metals until thoroughly cleaned.

5. Extreme care should be exercised in the use of cutting torches or welding for repairs. All collector parts should be cleaned thoroughly and access doors left open before such repairs are started.

DISCUSSION

Presiding: JAMES R. ALLAN, International Harvester Co., Chicago, Ill.

C. C. HERMANN¹ (*written discussion*): For many years our engineers have made a study of magnesium casting and machining operations, the dust and fume produced thereby, and methods for handling same. In view of our broad experience in the field, I should like to make the following comments upon the paper presented by Mr. Kane.

Magnesium dust problems have existed for a number of years. As far as the ease with which magnesium dust can be ignited, a spark, however produced, in the presence of magnesium dust deposits may produce a fire, and when water is present the hazard is intensified.

In considering the hydrogen generated from the reaction of magnesium particles and water, it must be remembered that magnesium stored under water produces hydrogen and the liberation of hydrogen at the surface of the water produces a hazard. Such systems must be vented by a pipe to the outside atmosphere. The author offers no indication that any liquid other than water may be associated with magnesium dust, for instance oil, to eliminate the hazard.

Mr. Kane, in his remarks on stand grinding, polishing and buffing, states that the "dust collecting system should be of unit type employing water." Certainly this is a biased opinion which completely ignores existing systems that are working satisfactorily on groups of machines, employing oil as the wetting agent and using oil sprays at the wheel location with oiled ductwork. No mention is made of vent pipe, in the case of water used as the wetting agent, to vent hydrogen to the outside of the building—a very unfortunate oversight on the part of the author.

In his treatment of flexible shaft grinding, Mr. Kane again fails to incorporate mention of vent pipe to carry liberated hydrogen to the outside of the building, in the event that water is used as the wetting agent. However, such an outside vent is not required with oil. Another important omission is the fact that a hazard exists in moist material clinging to under-surfaces of the grille and in passages within the bench. Also, there is no mention that such a bench must be capable of easy dismantling for thorough cleaning at frequent intervals. A wa-

¹ Claude B. Schneible Co., Chicago, Ill.

ter-wet bench becomes a definite fire hazard after a brief period of use and must be thoroughly cleaned.

The consideration of oil versus water, as a dust collecting medium, implies a suggestion that excessive loss of oil is experienced, whereas such is not the case with equipment properly designed to use oil. A rotating mechanism, such as a fan having a high peripheral velocity, will produce excessive losses of oil, due to atomization. In the ideal system, velocity is low, the pressure not exceeding $\frac{1}{2}$ -in. water gauge, with the result that no atomization of the oil takes place.

Mr. Kane's comparison of oil and water is decidedly inadequate to judge the relative advantages of the two in collecting equipment for magnesium dust.

DR. E. M. ADAMS²: Perhaps I can give more definite information on several of the substances that occur in magnesium foundries which may be the cause of questions.

The first one I would like to mention is magnesium oxide. It is peculiar to magnesium foundries. Some questions will be raised concerning the production of a condition by this magnesium oxide which is very similar or identical with that produced by zinc oxide. I believe that most of you are familiar with so-called "zinc chills."

It has been possible in a laboratory, experimentally, to produce with magnesium oxide fume a similar or identical condition. However, I do not believe that it is a practical problem in the foundry. I have been inquiring everywhere trying to find a single instance of its occurrence, and I have not yet found one.

Practically, magnesium oxide is not a problem with regard to the production of magnesium alloy castings. In our foundry, analyses that I have made have shown from zero to in the neighborhood of 30 milligrams of magnesium oxide per cubic meter of air. You will find that a number of workers are accepting, for magnesium oxide, the same limit as is accepted for zinc oxide, namely 15 milligrams per cubic meter of air. I believe, for an average exposure, there should be no difficulty in meeting that figure, although it may be low.

Another substance I would like to mention briefly is fluorine. In founding, where fluorine compounds are used as oxidation inhibitors, the following are the sources of exposure.

First is the fluoride spray, so-called, used for treating cores. That operation should be conducted in a ventilated booth, just as for spray painting. The primary action that this spray will have is one of local irritation in the upper respiratory passages. It could produce a chronic fluorosis over a long period of time.

The other exposures in the foundry result from the fume or smoke that comes from molds shortly after being poured, from the fume and smoke at the hot shake-out, and from hot castings shortly after the shake-out. The fume and smoke at those points are the sources of fluorine which result in exposure out on the foundry floor.

In the case of the smoke that comes from the mold after the pouring, a simple practice we have found is very useful. As soon as the ex-

² Biochemist, Dow Chemical Co., Midland, Mich.

posed metal has solidified, cover the top of the mold with a good layer of molding sand. That, apparently, effectively condenses the fluorine that would otherwise escape to the air.

Shake-outs should be well ventilated. We use a side hood about 6 ft. long, about 5 ft. high, with an air flow of about 20,000 cu. ft. per min. of air. The hood is at the side of the shake-out grate, which also has a down draught. The down draught serves only to prevent fumes coming up through the grate.

The fluorine that comes from the hot castings beside the shake-out is not very heavy. However, it is appreciable and might result in exposure of men, if men are working too close to it. General room ventilation serves, to a very large extent, to handle the fluorine that is in the air.

I believe that the fluorine presents a definite hazard, but it is not a serious hazard, nor a serious problem to handle.

I would like also to mention magnesium metal. In the past few years there has been considerable furor concerning the hazard presented by magnesium metal, small splinters, chips or whatnot cutting the skin. We have received reports of apparently very serious conditions from Germany.

Examination of evidence that we have on the effects of magnesium metal do not give us any basis whatever for drawing the conclusions that the Germans apparently did. As near as we can tell, the conditions which they report were not due to the metal and it is quite possible that they were due to the protective oils that were used on the metal. There has been a tendency to blame the magnesium for this condition, but the reports that we have show that dural, an aluminum alloy, has been the source of the greatest amount of difficulty. I believe that there has been a tendency to over-emphasize the metal composition.

Dr. Schwartz of the United States Public Health service, a year or so ago, surveyed a number of airplane plants. He was looking particularly for this condition. He could find only dermatitis due to the protective oils, to which he referred as "line oil" and "fish oil."

E. R. FISHER²: What degree of concentration of humidity do you find in a room where the wet collectors discharge directly into the room?

MR. KANE: I cannot answer the question specifically because the concentration, or the increase in humidity, from wet collectors where the air is recirculated is a function of the particular evaporative rate of the collector, the size of the room, and the amount of infiltration or exhaust air. The increase will vary with each plant. For a given plant, it is possible to determine how much moisture the particular collector will throw into the workroom atmosphere, estimate the amount of waste air, either through infiltration or through exhaust systems, and from those figures the rate of increase in moisture content that can be anticipated may be calculated.

From such figures rather accurate conclusions can be drawn and an

² Whiting Corp., Harvey, Ill.

increase in humidity to the point of causing condensation can be prevented.

We would never recirculate from a wet collector in a small room that was hermetically sealed because, obviously, air eventually would become saturated.

MR. FISHER: What is the largest group using recirculated air you know of per given cubic space?

MR. KANE: In most places where magnesium is being used, space is not confined, although a lot of exhaust equipment may be confined in a given area. That would indicate that if we took just the area covered by the plan dimension of the collectors we would have a high ratio between volume of air handled and plan area. Such a factor would be misleading. I have seen 40 wet-type benches, of the type illustrated in the paper, which were exhausting flexible shaft grindings and were located side by side. Those benches are 8 ft. long and they handle, roughly, 4000 to 5000 cu. ft. of recirculating air per min.

MR. FISHER: In that same room, were there other exhaust equipments exhausting to the outside?

MR. KANE: Yes, I know of few places that do not have a tremendous amount of exhaust to the outside from melting and heat treating furnaces, anodizing or pickling tanks, and sand blast operations.

In air conditioned plants there is less danger of humidity increase. The moisture content is controlled by the conditioning equipment which removes sensible heat either by reducing dry-bulb temperatures or water vapor content.

MR. FISHER: The general policy is not to exhaust to the outside?

MR. KANE: That varies with the individual plant and with State and local conditions. Magnesium dust, as such, does not enter into the toxic range that silica dust would. Magnesium dust is what those dealing with dust control would call "relatively coarse particles." Fine magnesium is collected easily because the particles are still relatively large and consequently the efficiency of magnesium collectors is exceedingly high.

MR. FISHER: In the grinding operation, do you exhaust to the outside?

MR. KANE: In the majority of cases, we recirculate from magnesium grinders. The exception is in States where such recirculation is prohibited or where the customer believes that all exhaust from dust collectors should be discharged outside.

MR. FISHER: When using oil for the liquid, from a consideration of building up oil fumes, would you have to exhaust?

MR. KANE: In our experience in the laboratory we have been unable to use oil in a dust collector without producing oil vapors which would necessitate outside discharge.

MEMBER: Do you use the same air volume for magnesium dust as for other dust?

MR. KANE: Yes, with the possible exceptions that I mentioned, namely: Sometimes it is not possible to put a hood on a wheel for grinding magnesium as effectively as is possible in ferrous work, because a man

can grind a much larger-sized magnesium casting at a stand grinder.

As far as conveying velocities go, the velocity given in the A.F.A. CODE OF FUNDAMENTALS OF DESIGN, CONSTRUCTION, OPERATION AND MAINTENANCE OF EXHAUST SYSTEMS will convey particles generated in ferrous and non-ferrous grinding and, therefore, will certainly convey magnesium. Such conveying velocities are far above the critical velocities. Hence, a factor of safety of at least 100 per cent exists when we talk about conveying velocities between 3500 and 4500 cu. ft. per min.

MEMBER: Magnesium dust is so much lighter than other dust would be. What velocity do you use?

MR. KANE: We use 4500 cu. ft. per min. in the branches. Specific gravity has relatively little effect on the conveying velocity required for small particles. The surface area is so great in relation to their weight that it is the surface area that largely determines the velocity of fall and consequently the conveying velocity.

M. E. BROOKS¹: I would like to add to Mr. Kane's statement with regard to the desirability of recovering the residues in sawdust. There is an economic factor there. When those materials are not recovered in a foundry producing a large quantity of material the loss can amount to a fairly large percentage. Those materials do have recovery value of metal in ingots to the extent of 50 to 60 per cent.

MR. KANE: One of the main reasons for not exhausting band saws and rotary saws is the salvage value of the collected chips in a dry state. I have tried to get estimates on lb. of magnesium per lb. of castings going through the sawing department of a plant. I also have asked myself the question "Does the salvage value justify the added maintenance and nuisance value and the distractions and lost time that will be caused if a fire occurs in a pile of chips?"

For example, on rotary filing benches, on one installation (which I do not offer as being indicative) we collect in a wet state material, which when dried, amounts to 100 lb. per week. That is from only two operators, and it is a combination of fine and coarse dust. I cannot tell you what per cent of that represents rotary filing.

In the sawdust, I definitely agree with Mr. Brooks on the volume of material involved. One company kindly measured the amount of sawdust from their saw department over a period of three days. It turned out to be 1300 lb. from a total of 44,000 lb. of castings. Roughly, that is about 3 per cent.

MR. BROOKS: We haven't made any attempt to recover metal from the wet state. We do not collect filing and sawdust any way except dry. On the volume of material that is formed of rotary filings and sawdust, I believe it is in the order of 1.5 per cent of the castings shipped. When you consider that about 60 per cent of that is recoverable it amounts to quite a volume of salvage.

MR. KANE: I can appreciate this recovery angle. However, I look upon clean working conditions as being conducive to continued production and worth a certain sacrifice. Sometimes improved working conditions provide an intangible asset that may or may not compensate

¹ Dow Chemical Co., Midland, Mich.

for loss in dollars and cents, due to not salvaging the material.

Certain customers are aware of the loss when they are using wet collectors and feel that the gain in housekeeping, better working conditions, etc., may offset it.

MR. BROOKS: From the fire hazard standpoint, I do not think there is any advantage in a collector for the rotary filings or band saw dust. We have never had a fire in our rotary filing division. We used to have a lot of fires on band saws until we changed our guides. Since then fires are very infrequent.

MR. KANE: That has been the impression I have had from talking to people working in magnesium. However, you may exhaust files and saws for the same reason that we are exhausting portable grinding operations on steel castings. No hazard exists there, and yet it is a nuisance and people are beginning to insist that these nuisance jobs be cleaned up, just in the general trend toward improved housekeeping.

MR. FISHER: I would like to ask Mr. Thrune what experience his company has had with that wet collection system wherein the duct was wet.

MR. THRUNE: I presume that you mean a system where the duct from the grinder over to the precipitating unit is wet. We had a system like that. It was first put in operation 10 to 15 years ago. It is our general conclusion that it was not successful. We have discarded all but one of those installations and we will discard that as soon as new equipment arrives. I suppose that such systems can be made to operate successfully but there are quite a few more "bugs" in them than there seem to be in the unit type so we have just discontinued their use.

MR. FISHER: It is almost impossible to move the material through a wetted pipe. Tremendously high velocities are necessary.

MR. THRUNE: I believe so. The system that we had consisted of a spray head underneath the wheel with the water from that spray running down to the bottom of the duct. There would be little edges that were partially wet and partially dry and the dust would collect there. Also, under the wheel there would be a wet space and a dry space and a half-wet space where the dust collected. There were too many such places throughout the system.

MR. BROOKS: The only thing I would like to add to Mr. Kane's statement in regard to the lodging of the dust on the ledges in the water wet collector is this: When we first installed our unit type equipment about 2½ years ago, the contractor installed it in such a way that the pipe from the collector back to the wheel had an elbow in it. That type of collector is apparently different from Mr. Kane's in that the water from the collector came back down that pipe, and after several days of operation the pipe was nearly plugged with wet dust.

The operator, grinding a casting with a wire, struck a spark and the wet dust ignited. I believe that is a very good proof that Mr. Kane's fear of danger from material forming on the ledge is not well founded because the suction was sufficient to take care of that fire. The first ignition impulse scared the man who was grinding pretty badly, but the fire never got to him. It got to the edge of the wheel and then the suc-

tion pulled it all back into the collector. The pipe was red hot when the fire was through. That type of collector, we feel, is absolutely safe.

MR. KANE: I like to hear that. Such experiences are things which people in our position never hear. If a committee of A.F.A. could get together with the idea of trying to assimilate all of this information and would listen to the experiences of some of the fabricators of magnesium, I believe they would draw much better conclusions than in the case where an outside concern gets certain limited information and begins applying it a little too generously at times.

I cannot over-emphasize it, because I am certain that within the next few months we are going to have codes promoted covering magnesium handling.

MR. BROOKS: In regard to that question of water or oil as a wetting medium. Oil is a messy material and involves a lot of trouble that the water collector does not involve. We have run these collectors of ours with water for 2½ years now and have had no trouble. I have seen water installations in a lot of foundries and have never found any that have caused trouble.

MR. KANE: I have seen a tentative recommended code of good practice where oil is to be placed in the preferred category. I believe that is very premature. Oil and water can both be considered as safe fluids. I do not think that there is justification for pushing a new fluid as being the only acceptable one without considerably more study.

CHAIRMAN ALLAN: Would you like to say whose code contained that list of suggestions?

MR. THRUNE: I believe that the code in question is the one that is being formulated by the Committee on Dust Explosions, National Fire Protection Association. I have seen numerous copies of it. No one has ever told me to keep quiet about it, so I think I can speak quite freely.

The committee is under the chairmanship of Hylton R. Brown, U. S. Bureau of Mines, College Park, Maryland. Three-quarters or more of the code is devoted to the control of magnesium dust in dust producing establishments. By that I mean establishments that are grinding dust to be used in incendiaries, fireworks and general purposes of that kind. Such plants have had a lot of trouble with materials because the people who make such products do not have any trouble when they mix up a batch of 100 lb. It works fine so they say, "What is the use of mixing it in these small batches when we can mix it in 1000-lb. batches?" Soon they have an explosion and build a new plant. That code is designed to correct that type of abuse.

Referring again to oil versus water, I might say honestly that I am not the oil advocate that I was a year ago. I believe oil should be considered as a possible precipitating medium, but it is not foolproof. If it were possible to remove the oil from the air again, I believe oil would work.

A dust collecting company should not condemn it too harshly because it does not fit into their present collectors. The present collectors are designed to make a kind of a froth through which to draw the air and dust. In it there is a system that makes a froth and through

that they drive the dust. The froth is water and is necessary because water does not wet the dust very readily.

I am suggesting that since oil wets magnesium so readily, there is no use of making all that froth and putting the oil into the air to start with. Impingement plates or something like that could be used.

The committee previously referred to has taken oil as a very fine medium because it is possible to perform experiments very easily to show that oil is a much safer medium than water, but industrial practice over a couple of years has indicated very strongly that water is satisfactory.

CHAIRMAN ALLAN: What have foundry operators to say about this code to date?

MR. THRUNE: I am not sure except that our company, as a foundry operator, has been given chances to look at the code, criticize it and return it with our corrections.

CHAIRMAN ALLAN: I wonder if I could get a copy?

MR. THRUNE: I would suggest that you contact Mr. Hylton Brown, U. S. Bureau of Mines, College Park, Maryland. The code is to be adopted finally at the Chicago meeting of the American Fire Protection Association.

MR. FISHER: Is that code we have been discussing to be applied to foundries or just merely these establishments that grind magnesium dust?

CHAIRMAN ALLAN: It will be a rule of the insurance carriers.

MR. FISHER: It will apply to foundries, too?

CHAIRMAN ALLAN: That is why it is so important that a large number of employers look these things over. Occasionally, we have to go in and knock out some of their codes as unworkable because they are not close enough to the industry.

I think that we have had a wonderful expose of some precautions that employers should take, whether in foundry operations or machine shop operations.

I certainly want to thank these gentlemen who have spoken to us this afternoon and given us for the record points that we can recommend and will be valuable as a reference on general practice of the A.F.A.

MR. KANE (*author's closure*): Many of the criticisms raised by Mr. Hermann have been discussed rather thoroughly in my paper and in the discussion which followed the meeting. Answers to his comments can be divided into the following headings:

1. The use of water as a collecting medium for magnesium dust as stated in paragraph 4 of my paper "Magnesium in a flooded state stored under water cannot be ignited." This is a flat statement and recognizes that water with magnesium becomes a fire hazard only when magnesium is slightly dampened with water, in which case it does burn at an increasing rate. Where an excess of water is used this condition no longer applies. For verification of this statement I refer to a discussion by Mr. Thrune of Dow Chemical Co. before the National Safety Council, reprinted in NATIONAL SAFETY NEWS, November 1942: "While

a little water on magnesium alloy dust adds to its burning properties, an excess of water absolutely prevents burning. ——— If the water is present in the dust in sufficient quantities (more than 50 per cent) it is impossible to ignite the metal since the water prevents it from being raised to its ignition temperature."

Substantiating Mr. Thrune's test and observations are the successful installations of literally hundreds of magnesium collectors using water. The comments of Mr. Brooks are typical of safety experience which foundrymen have had with collectors using water.

2. The generation of hydrogen was discussed in paragraph 4 of my paper. The quantity of gas so generated by the reaction of magnesium and water is so diluted that it can be safely vented to the workroom. Such venting is automatic and requires no special devices as the lighter gas is free to rise in any collector design and automatically vent itself as formed. Tests and experience have indicated that there is no necessity for venting collectors to the atmosphere. The lack of such a detail on magnesium collectors manufactured by at least eight manufacturers and involving the installation of hundreds of unit collectors and the approval of the National Fire Protection Association in their CODE ON MAGNESIUM DUST will verify this conclusion.

I would like to again emphasize the situation described in paragraph 1 of my paper, that theoretical generalities concerning the reaction of magnesium with water and the exaggerated emphasis on the formation of hydrogen when magnesium is wet has been the cause of much confusion which impeded progress in arriving at effective standards for magnesium dust control.

3. Regarding unit systems versus central systems there can be no question but that the use of unit systems in connection with magnesium dust control is the safest sort of system that can be installed. With the introduction of numerous unit-type collector designs the use of unit systems has become definitely practical.

Under this condition, it seems poor practice to install a central system which has the following possible disadvantages:

- A Central systems provide opportunities for accumulations due to poor air distribution, poor duct design, addition or change of branch connections to the system.
- B Exposes larger area and more personnel to hazards should a fire occur at any one point in the system.

I know of plants that are exhausting magnesium grinding operations through central systems using dry collectors. Such systems have been in service for a period of years, and yet the fact that no difficulty has been encountered could hardly be offered as an argument for the safety of such systems in the light of experiences in other plants where central systems and/or dry collectors have been employed.

4. With reference to grinding benches I must take exception to Mr. Hermann's statement that "a water-wet bench becomes a definite fire hazard after a brief period of use." Contrary to his description there is no reason for accumulations of moist magnesium on under-surfaces

of grilles or passages in the benches of collectors as manufactured by a number of companies today. Again the installation of hundreds of such benches employing water with complete safety over an extended period makes the degree of such hazard distinctly questionable.

5. As for oil versus water I believe that the loss of oil vapor will continue to be the biggest problem in the adaptation of oil to the collecting media of a magnesium dust collector, and to my knowledge this condition occurs on all collectors designed to date. Mr. Thrune and Mr. Brooks, in their discussion of my paper, have pointed out other disadvantages in the use of oil that must be weighed in comparing the relative advantages of oil versus water as a collecting media for magnesium dust.

Health Aspects of Magnesium and Other Foundries

BY WARREN A. COOK*, CHICAGO, ILL.

INTRODUCTION

1. Maintenance of health of workers is assuming increased importance in these days of man-power shortages. Whether we consider the newer operations of magnesium founding or the old-time practices still being conducted in many brass foundries, health is a vital factor in successful production.

2. A number of distinct advantages occur where high health levels exist among the personnel. Workers are more alert and capable physically, and are easier to get along with from a psychological point of view. Both of these factors help production. Reduction in absenteeism cuts losses incident to idle machinery, shifting of employees, and training additional workers. Provision of good working conditions assists favorable industrial relations.

3. Furthering the health of the worker can be approached from two angles: through an educational program to interest and inform him in healthful habits, and through the provision of healthful working environment. Let us first outline a number of ideas for the development of healthful living habits among workers.

DEVELOPMENT OF HEALTHFUL LIVING HABITS

4. We have found that an integrated program, presenting a specific subject covering some one phase of healthful living, will aid in improving healthful living habits. This program can be presented at safety meetings or through public address systems in plants. The interest factor must be very high. If a group of men should summarily be directed to get the proper amount of sleep every night, their reaction can be imagined. If this very vital element in the healthfulness and alertness of a worker is to be put across to a group of foundrymen, or any other industrial group, it is necessary to present it in such a manner that it will be acceptable. Whether it is a matter of getting enough sleep, of keeping emotionally balanced in these hectic days, or of giving more attention to a balanced diet, an effective program must have appeal if it is to be taken seriously by the worker, and it must have continuity if it is to have lasting results.

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5. One of the devices which is being used is the strip film talkie. Through this visual education method, considerable strides are being made in getting people to think about these health factors that they would otherwise tend to pass off with a shrug of the shoulders.

6. So that the enthusiasm of the moment will not lapse when the meeting is over or the public address record has been brought to a close, folders are distributed covering the specific item being treated that month, whether it be tuberculosis or prevention of the common cold. Just one item is the subject for the month. A functional poster bearing the month's calendar serves to keep the subject before the workers. The discussion at safety meetings during the month features this one subject. We cannot change living habits overnight, but we can bring a well directed program to serve as a strong influence in the improvement of healthful living practices.

7. In large plants, full-time medical departments are doing more and more to further the general health of the workers. The non-occupational disability is being recognized as responsible for about fourteen times the lost time of the occupational disability, and it is being given increasing attention by industrial groups.

8. Where the number of workers is too small for a full time industrial physician, industrial nurses, through their organizations, are interesting themselves in improving health levels of the workers. We feel that industrial managements should give more attention to this important factor in optimum utilization of manpower, and employ the facilities at their disposal to keep workers, not only on the job, but at highest working efficiency.

PROVISION OF HEALTHFUL WORKING ENVIRONMENT

9. The second phase of maintaining high health levels among workers is that of providing healthful working environment. In magnesium foundries, fluorides and sulphur dioxide may be present where certain operations are being conducted. What is not fully known are the effects which the fluorides and sulphur dioxide may produce, under foundry operating conditions, after prolonged exposure.

EFFECT OF FLUORIDE EXPOSURE

10. The action of fluorides on the body has been studied in the production of cryolite, in alumina reduction, and in connection with a number of other possibilities of absorption into the system.

They exert an irritative action on the skin and mucous membranes, which has been the cause of complaints among magnesium foundry workers.

11. In the publication of a well conducted study of atmospheric contamination from the casting of magnesium, Williams¹ reports that concentrations of fluoride in excess of 100 milligrams per 10 cubic meters caused a severe "biting" sensation in the nose, followed within a few minutes by a "runny nose" with considerable fluid. After about 20 min. blood may show on blowing the nose. This may persist for several days, and, in some individuals, may recur almost indefinitely. These effects are rarely of sufficient importance to report to the plant hospital. Williams¹ noted no such symptoms below 25 milligrams per 10 cubic meters.

12. This matter of local irritation can be readily cared for, but what of the long time action on the body of fluoride concentrations below the irritating level?

13. Roholm² demonstrated fluorosis of the bones among cryolite workers after prolonged exposure to more than 15 to 25 milligrams daily intake. In 1909, Ronzani³, an Italian physician interested in industrial hygiene, exposed animals to fluorides in the form of hydrofluoric acid. Using groups of 35 to 40 animals—rabbits, guinea pigs and doves—in each of several series of experiments, Ronzani found no injurious action whatever after 6 hr. a day exposure for 30 days to 3 parts per million, or approximately 24 milligrams per 10 cubic meters. This figure has been listed by a number of the states as a maximum allowable concentration.

14. However, the method which Ronzani used for preparing his known concentrations of hydrofluoric acid in the air is described rather incompletely in his original publication, and leaves some doubt as to whether the air in the testing chambers may actually have contained appreciably more or less than 3 parts per million. Also, the 30 day exposure was hardly long enough to rule out the possibility of development of fluorosis of the bones. The close similarity between the concentrations suggested as the threshold limit by Roholm², whose work is very highly regarded, and by Ronzani lends credibility to the latter's conclusions, but the use of 20 milligrams per 10 cubic meters, or its equivalent of 3 parts per million, for fluorides, as existing in magnesium foundry atmospheres, should be considered only as a tentative limit.

¹ Superior numbers refer to references at end of paper.

15. These figures will continue to be much quoted, and it is to give some insight into the question of their credibility that we have gone into rather considerable detail concerning them.

16. Correlation of data on the concentrations of fluorides to which men are exposed over a long period of time with the results of physical examinations, augmented by x-ray of the bones and post-mortem examination for evidence of pathology, will serve as the best basis for determining toxic limits for this material in the foundry industry. There is some unpublished material on men exposed for more than 17 years to appreciable fluoride concentrations with no fluorosis on x-ray examination. Unfortunately, quantitative analytical data on these exposures were not obtained. Also, the amount of fluoride excreted in the urine is a measure of whether fluoride is being stored in the body, and it is probable that such data will, through further research, provide a means of determining definitely whether or not a given fluoride exposure may be causing injury.

17. For the present, every effort should be made to keep fluoride exposures as low as good engineering practices will permit, certainly below the amount which causes local irritation, to keep a record of the atmospheric concentrations in which the men are working, and to undertake such periodic physical examination as medical authorities recommend.

EFFECT OF SULPHUR DIOXIDE EXPOSURE

18. The action of sulphur dioxide on the body is well known as a primary irritant to the skin and mucous membranes. Although systemic symptoms are not ordinarily expected on prolonged exposure to moderately excessive concentrations of sulphur dioxide, a tendency to increased fatigue, shortness of breath on exertion and abnormal reflexes have been found in an exposed group. These findings would indicate that there may be some further action on the body than that of local irritation. Such effects of sulphur dioxide exposure are well discussed by Kehoe⁴ and his co-workers.

EXPOSURES TO ATMOSPHERIC CONTAMINANTS IN MAGNESIUM FOUNDRIES

19. Only two surveys of fluoride and sulphur dioxide exposures in magnesium foundries have so far been published. The first of these⁵ is more of a recording of data obtained than an extensive study for the deduction of general conclusions. Only four fluoride

and the same number of sulphur dioxide determinations were made.

20. It was shown that in the general foundry atmosphere at shake-out and core knock-out operations, the fluoride concentrations were less than 3 parts per million. During pouring a concentration of 7.2 parts per million was found. The sulphur dioxide exposures were not as favorable, the general room air on the molding floor showing 3 parts per million; the shake-out 15 parts per million; core knock-out 24 parts per million; and the pouring operation 35 parts per million. It was noted that the conditions existing during shake-out and pouring were excessively irritating to the investigators; that this irritation, particularly of the eyes and throat, persisted for several days.

21. These results are being presented merely as a bit of experience on this problem, but caution should be observed in drawing broad generalizations from such a small amount of data.

22. In the second published study¹ more data were obtained; determinations were made of the fluoride content of air in connection with the shake-out, molding, melting and core spraying operations.

23. Fourteen determinations were taken in connection with shake-out operations. Concentration varied from nine to 180 milligrams, with an average of 87 milligrams per 10 cubic meters. In molding operations 32 samples were collected. These averaged 18.8 milligrams, the lowest being 4.4 milligrams. The only high concentrations at molding stations were found adjacent to shake-out operations, and, in one such case, was as high as 106 milligrams per 10 cubic meters. Generally, these data indicated that the molding operation, in itself, does not present an excessive exposure to fluorides.

24. In melting operations, both the average of 12.6 and the range of 10 determinations from 7 to 17 milligrams per 10 cubic meters were within this suggested limit of 20 milligrams per 10 cubic meters. In the core spraying operation, ventilated booths were being used. This control measure, which is considered essential, kept exposures to fluoride below 10 milligrams per 10 cubic meters.

25. Thus we are beginning to develop some information on how much of these materials are present in foundry atmospheres. Such information will be extremely valuable as it is added to similar data for subsequent years and for other magnesium found-

ries. Then, as we begin to see the development or non-development of pathological reactions from these fluoride concentrations, we will have a body of specific information, taken under actual industrial operating conditions, on human beings, which will give us the facts as to whether this 20 milligrams per 10 cubic meters is the safe limit, or whether the limit should be set at a much lower or a much higher point.

26. Sulphur dioxide exposures found in this study were within the suggested limit of 10 parts per million. Although noticeable on first entering the foundry, the characteristic odor was apparent for only a few minutes. The average of 11 samples, varying from 1.9 to 7.1 parts per million, was only 5 parts per million.

LEAD EXPOSURES IN BRASS AND BRONZE FOUNDRIES

27. To discuss some of the health hazards other than those found in magnesium foundries, work has been in progress over the past year by a number of reputable investigators, among them Littlefield⁶, who are amassing an impressive amount of data on the lead exposures in brass and bronze foundries producing highly leaded alloys. The possibility of lead poisoning in the brass foundry has received scant attention in years past, but is today being accorded more thorough consideration.

28. The use of lead-in-urine determinations is proving of much value in indicating whether men engaged in foundry operations producing highly leaded alloys are exposed to too much of this metal.

29. The determination of lead in urine is not a good diagnostic measure by itself, but it is excellent in determining the amount of lead which is absorbed into the system. If all of a group of workers show less than 100 micrograms of lead per liter of urine in a series of single excretions of urine, the amount of lead absorbed in that particular operation is within safe limits. If the amount excreted is more than 100 micrograms of lead per liter of urine, but less than 200, it would be well to investigate the sources of exposure and reduce them, but even then poisoning would not be expected except in highly susceptible persons.

30. As concentrations of lead in urine begin to rise above 200 micrograms per liter attention should be given to reducing the exposures because the chances are that in a group of men some lead poisoning will be encountered.

31. In addition to determining the amount of lead per liter of

urine, another technic, which gives better data, is to obtain the amount of lead excreted per hour. This is done by having the worker void his bladder completely, the time being recorded, and then, after some convenient period of 2 or 3 hr., the bladder is again completely voided, this sample being saved for analysis. We then have the amount of lead excreted per hr. In the interpretation of the results, 4 micrograms per hr. correspond to 100 micrograms per liter.

32. This method is being used, not only in certain foundries, but also in other industries where there are lead exposures, and it is found to be very successful as a means of keeping in contact with the amount of lead that a man is absorbing.

DUST CONDITIONS

33. Today, with the great activity in foundries, with the long hours that men are working, and also with the fact that men are being rejected by the Selective Service System when they have a tendency toward a tuberculous condition, it is particularly important that foundrymen give attention to x-ray of workers before putting them on the job, and also periodic x-ray of men on the job.

34. In carrying out such an x-ray program we do not have to feel apprehensive, as we did perhaps five or eight years ago, that, if we found silicosis in a man's lungs, we immediately would have to find some other job for him. At the risk of reviewing a fact well known to most foundry operators, the point should be emphasized that simple silicosis is not a cause of disability in the foundry industry. If a molder is found to have simple silicosis, he should continue as a molder. An effort should be made to see that his dust exposure is well within safe limits, but usually this can be easily attained.

35. In keeping a man with simple silicosis on the job, it must be kept in mind that he is more prone to contract tuberculosis from a man who has an open tuberculous infection. With a periodic x-ray program the possibility of active tuberculosis in the foundry is minimized, and the incidence of disabling or fatal tuberculo-silicosis will be greatly decreased.

36. In addition to the check on the tuberculosis, the periodic x-ray of foundry workers will indicate whether there are certain unsuspected excessive dust exposures which are causing an increase in the development of fibrosis or in the extent of silicosis in the

workers' lungs. This will provide an opportunity to investigate the exposure and bring the dust under control before new cases of silicosis develop.

37. Now is the time to institute an x-ray program, if it is not already in progress. From the liability point of view, those foundries which are not x-raying their workers now, when there is a great deal of employment, are going to find themselves very seriously embarrassed when the employment level falls off. From an industrial relations point of view, if the procedure is properly planned, resistance of the individual workers and the union may be overcome. The men must be assured that they will not lose their jobs even if they have silicosis. They must be informed that this is for their protection and the protection of their fellow workers, that if anyone has active tuberculosis, the sooner it is found and the condition cared for, the sooner that man will be back on the job.

38. Resistance may persist where there is a background of lack of good faith in pre-placement together with periodic x-ray examinations among foundry workers, but instances can now be pointed to in numbers, perhaps most notably the Milwaukee experience where an x-ray program coupled with dust control has long been instituted and continued to the manifest satisfaction of both employer and employee.

CONCLUSION

39. The foundry industry has in the past been the subject of much loose talk, insofar as the severity of health hazards is concerned. The writer feels, in connection with this new magnesium foundry situation, that we want to avoid loose talk on the extent of the hazards and their severity. On the other hand, we do not want to become callous just because we do not see men dropping in their tracks or being taken to hospitals. We want to know what the facts are, take a common sense attitude toward them, and, where control measures are necessary, we want to see that they are properly applied.

40. With such an attitude and line of action, the hysteria which swept the industry in the first half of the past decade can be avoided when our next drop in industrial activity occurs. Not only will unfavorable events be avoided, but, through improvement of the health of the men and women in the industry through educational means and provision of hygienic working conditions, favor-

able results will accrue in the form of greater productivity, less absenteeism, and better personnel relations.

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Infra-Red Lamps Dry Green Sand Molds For War Castings†

By L. M. DURYEE*, WATERBURY, CONN.

1. In a Connecticut foundry, in a space 15 ft. wide and 30 ft. long, the molds for a total of 100,000 lb. of metal per month are dried effectively, uniformly and economically with infra-red lamps. The labor of 3 men, formerly using torches and charcoal for drying the molds, has been completely eliminated. The equipment for this fast drying of green sand molds was purchased in the form of standard R-40 reflector type drying lamps, and the investment was surprisingly low. The time for drying each green sand mold averages only 90 min., resulting in a uniform penetration of dryness to a depth of 1½-in. in the mold surface, and no labor is used during the drying.

PROCEDURE

2. The surprising results noted above are accomplished month after month in the small Krodel Foundry in Waterbury, Connecticut, where bronze castings are made for important Navy work. The radiant heat lamps are mounted on metal frames and spaced on 6-in. centers, the frames varying in size to effectively cover the various mold surfaces. Ten such frames are in daily use, totaling an electrical load of approximately 80 kw. Each frame, when not in use, is hung on the wall, ready to do its next job of drying. When in use, the frames are mounted horizontally over the mold, at a distance of 2-in. from the edge of the flask or cope, and the electrical cable is plugged into a near-by outlet. The molds themselves are laid on the floor, and since the skin-drying is accomplished so rapidly, mold drying floor space for the relatively large number of castings made is at an absolute minimum.

† In the absence of the author, this paper was presented by E. H. Robinson, Lamp Dept., General Electric Co., Nela Park, Ohio.

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FIG. 1—INFRA-RED LAMP FRAMES BEING MOUNTED HORIZONTALLY OVER SAND MOLDS FOR DRYING.

DEVELOPMENT

3. In 1941, the difficult problem of obtaining uniformity in skin-drying of the green sand molds in this small bronze foundry assumed important proportions. Castings for Navy specifications were difficult to make, and uniformity of surface smoothness was the keynote. When the writer learned of the difficulty being encountered in making the mold surfaces completely uniform in hardness and dryness, infra-red drying was suggested as the answer.

4. The first crude frame, made of wood, which held 6 R-40 drying lamps was a quickly made and rather rustic piece of equipment for the first test on green sand molds. When the lamp bank was installed horizontally above the cope, however, and then, later, on the drag, the instantaneous vaporizing of moisture furnished

ample evidence that the drying commenced within the first 30 seconds. Within 90 min., when drying was complete, the two parts of the mold were put together and the metal was poured. Subsequent machining and inspection of the finished casting showed that perfectly uniform mold drying had been achieved. Blow-holes were eliminated, and the casting met all inspection requirements. Now in use for over 15 months, radiant heat energy from infra-red lamps has proven, in this foundry, that it can dry green sand molds more uniformly, faster and more economically than any other method ever used.

EQUIPMENT

5. Lamps are mounted in porcelain sockets, and each socket is installed on a 3-in. outlet box. The outlet boxes are connected together with 3-in. nipples, $\frac{3}{4}$ -in. in diameter, to carry the wiring and to make a rigid frame. The frames contain from 30 to 50 lamps each, depending on the size. The lamps are rated at 250 watts and 110 volts and are wired so that two are always in series. Thus, three phase-220 volt power service is fed to the lamps, and no 110 volt lighting transformers are required, due to this series connection which reduces the installation cost very substantially. Eight outlets are installed at suitable intervals along the wall into



FIG. 2—INFRA-RED LAMP DRYING OF SAND MOLDS. WALL HANGERS AT LEFT SHOW INFRA-RED LAMP FRAMES NOT IN USE.

which the flexible cords from the lamp frames are plugged when the frames are put into operation.

6. The lamps, of course, are entirely open in the frames which hold the sockets, and no enclosure whatever is used. As soon as the moisture in the sand surfaces begins to vaporize, there is complete freedom of movement of the vapors upward between the lamps which, because of no enclosure, hastens the drying process materially. If drafts from an open door blow across the lamps, there is no reduction whatever in the efficiency of heat transfer, because radiation from lamps to sand surfaces continues uniformly, entirely independent of surrounding air temperatures. Since the rays from these lamps are parallel, there is no appreciable difference in the temperature of sand surfaces located at varying distances from the lamp-bank heat source. One portion of a mold cavity may be 12-in. distant from the lamps and another portion 3-in. distant, yet the drying rates of these surfaces are practically the same, due to parallel heat rays emanating from the source.

REASONS FOR DRYING SPEED

7. The unusual speed obtained with radiant heat infra-red lamps is due to two well known facts.

8. Stephen Boltzman's law of natural radiation states that the amount of radiant energy per unit area varies directly as the fourth power of the absolute temperature of the heat source. Thus, a filament of an R-40 drying lamp, operating at approximately 4200°F. (2316°C.), emits exactly 8 times the quantity of radiant energy per unit of area as does a 2100°F. (1149°C.) flame temperature source.

9. The other underlying reason for fast drying with infra-red lamps is the exceedingly large heat gradient between the 4200°F. (2316°C.) source and the sand temperature itself which usually reaches approximately 225°F. (107°C.).

MAINTENANCE COST

10. The maintenance cost consists essentially of lamp replacements, there being no other maintenance problems encountered. The great majority of other industrial infra-red lamp installations are extremely low in maintenance, because the lamp filaments are designed for high voltage, operating on a low voltage of 110 volts at the socket. The life of a filament, therefore, is al-

most limitless, there being no appreciable evaporation of the tungsten. However, in foundry practice it has been found that although no filament failure is encountered, the shifting of frames from the molds to the wall hangers has caused lamps to fail where the glass bulb is cemented to the brass shell. This has been corrected, to a large extent, by using lamps equipped with plastic collars which securely hold the glass and brass shell together as one unit.

ADVANTAGES

11. Infra-red lamp industrial applications have been speeding production for war all over the country. It has been only recently, however, that infra-red drying has found its way into foundry practice. A large midwest foundry, using over 400 infra-red lamps daily for mold drying, reports a 75 per cent reduction in labor costs, as compared with former methods when kerosene torches were used. This means not only a substantial lowering of the cost of finished products to our armed forces, but, what is more important, it is also releasing valuable man-hours for other productive work.

12. Paint baking and drying has, of course, been revolutionized as the infra-red method has swept the country, and now this fast drying method promises to materially increase foundry production as well, wherever it can be adapted to the skin-drying of green sand molds. It is no exaggeration to state that infra-red drying is fast becoming a top-flight production weapon for war and victory. Large foundries, as well as small, can give serious consideration to the inherent advantages of radiant heat mold drying, because every man-hour saved means just that much more production which, of course, brings the longed-for end of the war just that much closer.

DISCUSSION

Presiding: J. THOMSON, Continental Roll and Steel Foundry Co., East Chicago, Ind.

Co-Chairman: H. W. JOHNSON, Northwestern Foundry Co., Chicago, Ill.

E. H. ROBINSON¹ (*written discussion*): Mr. Duryee has had some very practical experience in the use of "drying lamps" with mold forms. It is always most interesting to hear from a man who has actually done things, and has had the courage to try out some new idea and make it work.

The purpose of this discussion is to describe briefly how the infra-red, or drying, lamp came into existence. To talk about the lamp itself always suggests other uses for it, and so we are mutually benefited. Also, we hope to supplement suggestions, as made before, in the application of the lamps to the specific job of drying green sand molds.

Over 86 per cent of the electricity turned through a filament lamp takes the form of heat. If 1000 watts are put through any incandescent lamp, 860 watts of the 1000 are going into heat, and heat only. The light from the lamp is derived from the watts left. In this case, 140 watts go into light.

It would seem, therefore, that the "heat" lamp, the "drying" lamp, and the "infra-red" lamp had been with us ever since Edison invented the filament lamp to produce light. While this is true, until recently we never thought of all this heat as having a function that could be utilized.

For 50 years lamp engineers have been trying to increase the efficiency of filament lamps. Every improvement in lamp design by manufacturers has been directed toward more light and less heat and, of course, lower price.

As far back as 1925, at a big outdoor picnic at Nela Park, Cleveland, headquarters of the G. E. Lamp Department, a group of engineers and salesmen were amazed to see nice, juicy steaks cook under the light and heat of big 1000-watt incandescent lamps. Those steaks were beautifully cooked. However, the cost of the electricity and the lamps, the time required to cook them, and the life of the lamps are factors which prevented the idea of cooking steaks with lamps from becoming a commercial possibility.

There are many jobs today, even with the lower prices of electricity, lamps and equipment, which cannot be done economically with filament lamps. In 1925 we did not suspect the unique possibilities of drying paint with radiant energy.

Lamp efficiency in lumen output varies with the life of the lamp. The present line of drying lamps has been designed to provide maximum radiation and to give long life—thousands of hours and upwards. They have heavy filaments and are ruggedly constructed to stand hard service. The wattages are 100, 250, 500 and 1000. Three different shapes are provided in 250 watts.

¹ Nela Park Engineering Dept., General Electric Co., Nela Park, Ohio.

All of the clear lamps are designed for use with gold or aluminum plated reflectors. One type has its own reflector of vaporized aluminum, and it would appear that this type might find many applications in core drying.

In any drying problem, the solution usually lies in how many watts per sq. in. are needed and which lamp and reflector system shall be used to get the right amount of heat most conveniently and economically. The plan of any installation must take all factors of radiant energy drying into consideration. Thus, we must include first cost, including accessories, kilowatts installed, operation cost, maintenance of oven and reflectors, as well as speed and convenience. All of these factors are pertinent to the valid use of drying lamps, and enable a choice from the several wattages and types best suited to specific jobs. Let us consider some of the techniques employing the vaporized aluminum type of reflector.

When the lamps are spaced to almost touch each other ($5\frac{1}{4}$ -in. centers) and located approximately 6-in. above a flat surface, the maximum energy per sq. in. of surface is almost 6 watts per sq. in. This is the highest watts per sq. in. obtainable from any of these sources where uniform coverage is obtained. The reason is obvious. The energy from such lamps overlaps the energy from the adjacent lamp to form a uniform heat pattern, formed by the focusing effect of each reflector lamp.

While it remains true that, by different focusing, there may be hot spots created which will exceed the 6 watts per sq. in. mentioned, usually, and in most applications, a uniform energy distribution is desired. In other cases, it may be highly desirable to have variable watts per sq. in. to alter the temperatures either by wider spacing, greater distance from the work, or throwing the heat lamp out of focus with its reflector. All of these effects may be obtained by the intelligent use of the right drying lamp and the correct reflector.

JOHN HOWE HALL²: This account of the infra-red drying lamp is exceedingly interesting; however, the point that occurred to me is that the author seems to completely ignore the wide prevalence of the oil-burning or gas-burning exterior heaters with which molds are dried with warm air. These types of drying units are used largely in the foundries making heavy work.

The cost of infra-red heating as compared to manual manipulation of a torch is favorable, and the savings are very great. However, when compared to setting an oil heater going and leaving it for a day or two while the molds dry out, the cost picture is not so favorable; the heater would be more economical.

However, in many large molds which are dried with air, it is difficult to get proper drying in deep pockets where the air does not circulate properly. I had hoped that it did not make much difference how far above the pocket the lamp was, that I could drive the heat down there, but I was disappointed to learn that the drying lamp had to be within 6 in. of the surface. Do you know, or does anyone know, of work of

² General Steel Castings Corp., Eddystone, Pa.

that type on which drying lamps have been used to help out the air heaters?

MR. ROBINSON: I do not know of an installation for a specific problem of that kind. However, when a lamp has a 30° cut-off a lot of cross rays will go down into the mold. It is the application of the inverse square law, namely, light varies inversely as the square of the distance from the source. That rule also applies very closely to infra-red energy.

I would not be a bit surprised but that some day we may have a lamp or a mechanism, a reflector plus a lamp, that could hit a spot down deep in the mold. We are in the development stage now. It is very promising that we may devise lamp equipment for a specific deep mold, because the rays will certainly go any place that they are directed.

MR. HALL: The rays will go down and the air will not?

MR. ROBINSON: That is true, but the ambient temperature created by that number of kilowatts will assist air movement. I cannot think of a single lampoven manufacturer, outside of possibly one, who has tried to develop an oven which would make the core drying a continuous process. This can and should be done.

We do adjust watts per sq. in. on differently shaped objects in the painting industry. I cannot see why the proper application of the lamps, either by focusing or positioning the lamp in a proper reflector, would not hit pretty deep into a mold.

MR. HALL: I happen to be talking about molds that are big enough to keep house in, where the mold is its own oven. In such molds there are pockets where it is difficult to get the air to circulate.

MR. ROBINSON: I believe that the problem is merely a variation of the present process of delivering higher watts per sq. in. to a particular part of the deep core by connecting more energy where it is needed.

MR. DURYEE (*author's closure*): As stated in my original article, heat radiation from the 250 W., R-40 reflector type lamp is not subject to the inverse square law because the energy comes largely from the reflector in the lamp, and not from a point source. The rays are almost horizontal, so it is not at all necessary to keep the lamp within 6-in. of the sand surface. In practice we have found little if any difference in sand-surface dryness, whether the sand was in a cavity 12-in. from the lamp, or on a flat mold surface 2-in. from the lamp. The rays will go down to any distant point within 12-in. to 15-in. away from the lamp and dry the sand surface satisfactorily.

This statement is based on practical results being obtained daily—not merely a conclusion based upon theory. The inverse square law must be discarded completely when R-40 reflector type lamps are used, because the “inverse” law applies only when the heat (or light) is emitted by a point source.

